Technical Report CHL-99-14
July 1999

US Army Corps of Engineers
Waterways Experiment Station

Hildebrand Lock and Dam

by Howard Park, Michael Trawle

Prepared for U.S. Army Engineer District, Pittsburgh

US Army Corps of Engineers
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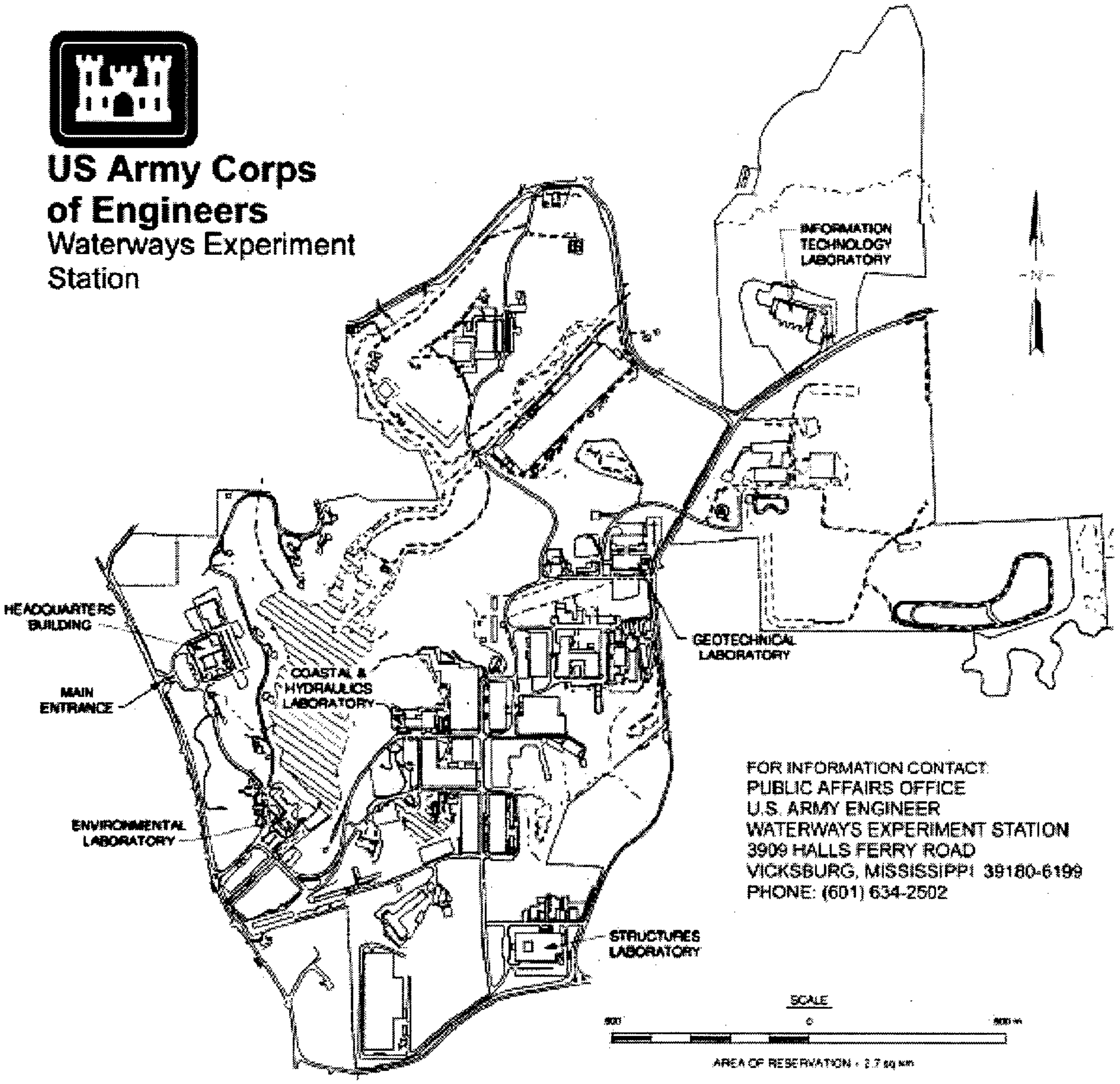

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Waterways Experiment Station Cataloging-in-Publication Data

Park, Howard E.
Hildebrand Lock and Dam / by Howard Park, Michael Trawle ; prepared for U.S. Army Engineer District, Pittsburgh.
96 p. : ill. ; 28 cm. — (Technical report ; CHL-99-14)
Includes bibliographic references.
1. Hydraulic structures — West Virginia. 2. Monongahela River (W. Va. and Pa.) 3. Hildebrand Lock and Dam (W. Va.) 4. Sediment control — West Virginia. I. Trawle, Michael J. II. United States. Army. Corps of Engineers. Pittsburgh District. III. U.S. Army Engineer Waterways Experiment Station. IV. Coastal and Hydraulics Laboratory (U.S. Army Engineer Waterways Experiment Station) V. Title. VI. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; CHL-99-14.
TA7 W34 no.CHL-99-14

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Preface

The model investigation described herein was conducted for the U.S. Army Engineer District, Pittsburgh, by the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, a complex of five laboratories of the Engineer Research and Development Center (ERDC). The study was conducted in the Hydraulics Laboratory of WES during the period February 1994 to January 1996. In October 1996, the WES Hydraulics Laboratory merged with the Coastal Engineering Research Center to form the Coastal and Hydraulics Laboratory (CHL). Dr. James R. Houston is the Director of the CHL.

During the course of the model study, Messrs. Walter LePut, Ray Povirk, and Mark Zaitzoff of the Hydraulic Design Section of the Pittsburgh District and other navigation interests visited WES at different times to observe the model and discuss test results. The Pittsburgh District was kept informed of the progress of the study through monthly progress reports.

The model study was conducted under the direct supervision of Dr. L. L. Daggett, Chief of the Navigation Division, Messrs. Michael Trawle, Chief of the Rivers and Streams Branch and Thomas J. Pokrefke, Research Hydraulic Engineer. The principal investigator in immediate charge of the navigation portion of the model study was Mr. H. E. Park, assisted by Messrs. Ronald Wooley, Edward Johnson, and James Sullivan and Ms. Debby George, all of the Navigation Division. This report was prepared by Mr. Park and Mr Trawle.

Commander of ERDC during preparation and publication of this report was COL Robin R. Cababa, EN. This report was prepared and published at the WES complex of ERDC.

Conversion Factors Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
miles (U.S. statute)	1.609344	kilometers
square miles	2.58998	sq kilometers
tons (2,000 pounds, mass)	907.1847	kilograms
pressure (1 lb/ft^2)	47.85	Pascals (n/m^2)

1 Introduction

Location and Description of Prototype

Hildebrand Lock and Dam is located on the left descending bank of the Monongahela River about 108 miles[1] above the "Point" at Pittsburgh, PA. The lock and dam are about 8 miles south of Morgantown, WV (Figure 1). The principal structures existing at the site include an 84-ft by 600-ft lock and a 530-ft long gated dam. The pool created by the gated dam extends the Monongahela River system upstream about 7.5 miles to Opekiska Lock and Dam.

The Monongahela River system is formed by the confluence of the Tygart Valley and West Fork Rivers near the city of Fairmont, WV, and flows in a northerly direction about 128 miles to its confluence with the Allegheny River at Pittsburgh, PA, to form the Ohio River.

At the time of this report, the Monongahela River system consisted of nine locks and dams that connect Pittsburgh, PA, to the head of navigation near Fairmont, WV. The Monongahela River locks and dams, from north to south, are 2, 3, 4, Maxwell, Grays Landing, Point Marion, Morgantown, Hildebrand, and Opekiska.

History of the Project

The original locks and dams on the Monongahela River system, 1 - 7, were constructed by the Monongahela Navigation Company from 1839 to 1886 and were acquired by the United States in 1897. From 1874 to 1903, slack water navigation was extended to the head of the river with original Locks and Dams 8-15. Since that time, several of the locks and dams have been replaced by one lock and dam structure. Hildebrand Lock and Dam is an example. It was constructed from 1956 to 1960 to replace original Locks and Dams 12 and 13 and placed into operation in 1959.

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[1] A table of factors for converting non-SI units of measurement to SI units can be found on page vi.

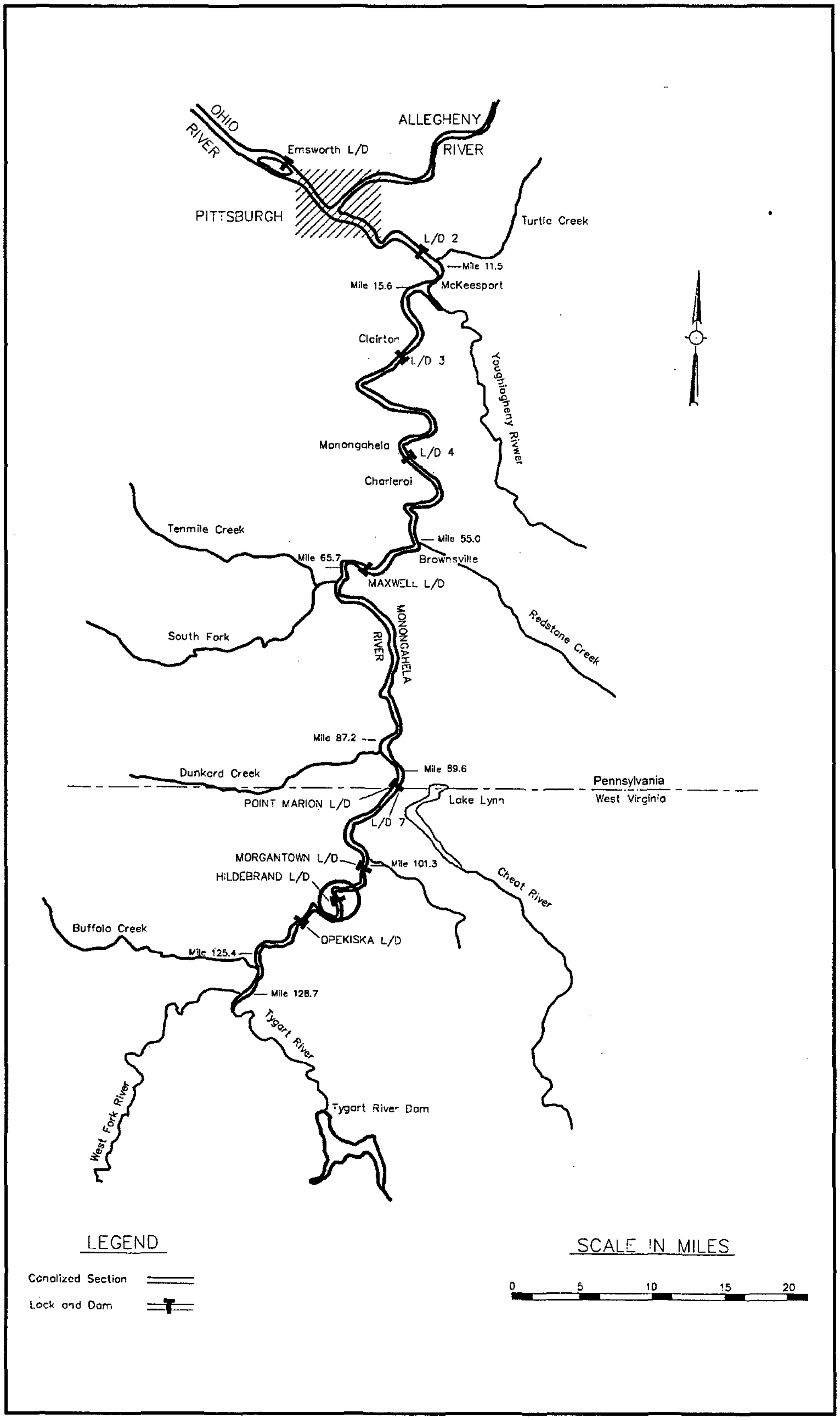


Figure 1. Site map

Need and Purpose of the Model Study

Because of the location of the Hildebrand project (downstream of a very sharp left-hand bend) and the uniqueness of the depositing sediments, it was necessary to use both a physical model and a numerical model to develop a plan that would eliminate or reduce tendencies for fine-grain silts and clays, intermingled with leaves and organics, from depositing in the upper lock approach to the Hildebrand Lock. The physical model was used to (a) ensure that the implemented plan did not have significant adverse impacts to navigation, and (b) to qualitatively observe depositional tendencies in the upper lock approach using potassium permanganate (liquid dye), polystyrene beads, and confetti. The numerical model was used to quantify deposition rates in the upper lock approach, both with existing conditions and with the implemented plan.

The physical model was also used to demonstrate the conditions resulting from the proposed design to the project sponsors, and to ensure the design's acceptability from a navigation standpoint.

2 Physical Model

Description

The model reproduces about 1.7 miles of the Monongahela River from about river mile 107.8 to 109.5 and the adjacent overbank areas that would contain riverflows to about elevation 850.0 ft (NGVD).[1] The model was of the fixed-bed type and the channel and overbank were constructed of a sand cement mortar and shaped to follow sheet metal templates that were set to the proper elevation. The model also reproduced the existing dam and the upper portion of the existing lock and lock walls. The lock and dam were constructed of sheet metal and set to the proper elevation. The channel portion of the model was constructed from a hydrographic survey dated October - November 1989 and the overbank was constructed from a topographic survey dated March - April 1990.

Scale Relations

The model was built to an undistorted linear scale of 1 ft (model) = 80 ft (prototype). This scale allowed for accurate reproduction of current magnitudes, cross-currents, and eddies, that would affect depositional tendencies and navigation. Other scale relations resulting from the linear scale are:

Characteristic	Ratio	Scale Relation Model : Prototype
Length	L_r	1 : 80
Area	$A_r = L_r^2$	1 : 6,400
Velocity	$V_r = L_r^{1/2}$	1 : 8.94
Time	$T_r = L_r^{1/2}$	1 : 8.94
Discharge	$Q_r = L_r^{5/2}$	1 : 57,243
Roughness	$n_r = L_r^{1/6}$	1 : 2.08

[1] National Geodetic Vertical Datum.

These scale relations allow measurements of current magnitudes, discharge, and water-surface elevations to be quantitatively transferred from the model to the prototype.

Appurtenances

Water was supplied to the model with a 10-cfs pump, which operated in a recirculating system. The discharge was measured by a venturi meter and controlled with a valve. Water-surface elevations were measured in the model with piezometer gauges connected to a centrally located gauge pit. The upper pool elevation was controlled with the gated dam and the tailwater elevation was maintained with the model tailgate at the lower end of the model.

Current magnitudes and directions were determined with cylindrical floats drafted to the depth of a loaded barge (9.0 ft prototype). Surface current directions were observed in the model using confetti. A remote-controlled model towboat was used to determine the effects of currents on tows entering and leaving the upper lock approach. The towboat was equipped with twin screws operating independently of each other and was propelled by two small electric motors with a battery in the tow. The towboat could be operated in forward and reverse and at scale speeds comparable to those using the Monongahela waterway.

Model Verification

With existing conditions, i.e., the lock and dam in place, the model was verified to prototype data furnished by the Pittsburgh District. These data were surface current magnitudes for a riverflow of 13,600 cfs. The results of the comparison indicated that the model reproduced conditions in the prototype with a reasonable degree of accuracy.

3 Tests and Results

The study of flow patterns, the measurement of current magnitudes and directions, the observation of depositional tendencies, and the effects of currents on the model tow were the primary concerns during this phase of the study. These concerns were addressed with existing conditions and the implemented plan.

Test Procedures

A representative selection of riverflows were used for testing based on information provided by the U.S. Army Engineer District, Pittsburgh. The following is a list of the riverflows that were used.

Discharge, cfs	Upper Pool Elevation, ft	Pool Condition
5,000	835.0	Controlled Pool
10,000	835.0	Controlled Pool
13,600	835.0	Controlled Pool
20,000	835.0	Controlled Pool
40,000	835.0	Controlled Pool
60,000	835.0	Controlled Pool
90,000	835.0	Uncontrolled Pool
120,000	837.4	Uncontrolled Pool

All riverflows tested were steady flow conditions.

Tests were conducted by introducing the proper discharge into the model and maintaining the proper upper pool and tailwater elevations for a given discharge. With base tests and Plan A, the upper pool elevation was controlled at model gauge 5 (in the lock forebay) and the tailwater elevation was controlled at model gauge 7 (Figure 2).

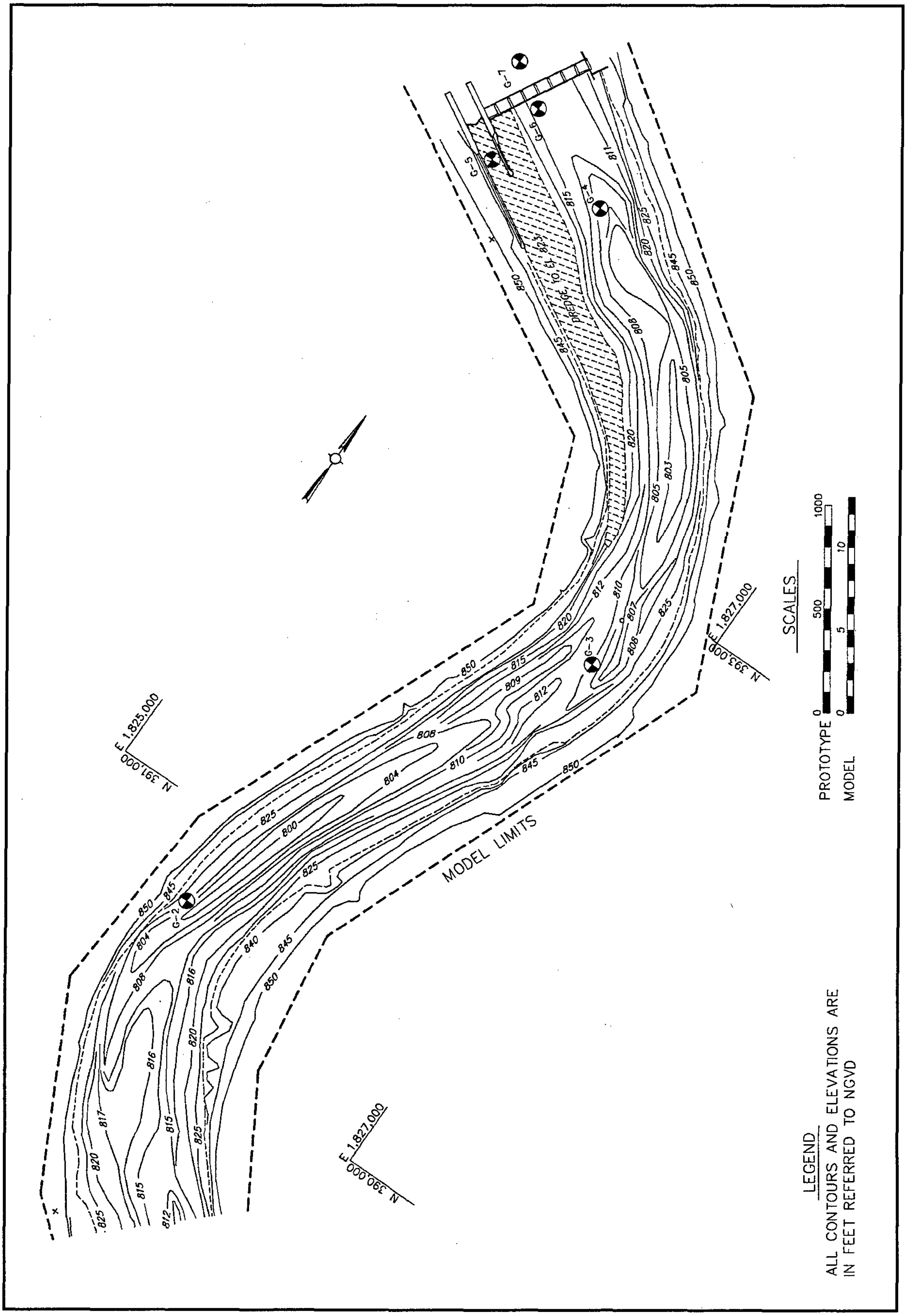


Figure 2. Base tests

Current directions and velocities were measured using a video tracking system. Current directions were determined by plotting the paths of the floats, and current magnitudes were recorded by timing the travel of the floats over a measured distance. In the areas where turbulence, eddies, and crosscurrents exist, the plots only show the main trends in the interest of clarity.

A model towboat, representing a pusher 120 ft long and a six-barge flotilla (78 ft wide by 350 ft long), was used to demonstrate navigation conditions for tows entering and leaving the upper lock approach. The video tracking system was used to track the path of the model tow through the study reach.

Existing conditions were fully documented using the physical model. These data from the physical model (i.e., current direction and velocity and water-surface elevations), along with the sediment analysis, were furnished for input to the numerical model such that deposition rates, deposition patterns, shear stresses, and threshold velocities could be computed for the existing conditions. Once the threshold velocities for scour and deposition were attained from the numerical model for the existing conditions, several intermediate tests were performed on the physical model. The purpose of these tests was to develop a dike field that would increase velocities in the upper lock approach which would reduce or eliminate deposition, and have the least adverse impacts to navigation. After development of the dike field, referred to in this report as Plan A, physical model data were again furnished to the numerical model to attain deposition rates and patterns with the implemented plan.

Base Tests with Existing Conditions

Description

Base tests with existing conditions are shown in Figures 2 and 3 and consist of the following principal features.

a. The upper portion of the 84-ft x 600-ft lock chamber adjacent to the left descending bank. The lock chamber had a non-ported landside guide wall extending to sta 6 + 47.5A and a non-ported riverside guard wall extending to sta 3 + 13.0A.

b. A 530-ft-long dam consisting of six 60-ft-wide gate bays, with crest elevation 816.0 ft and two 50-ft-wide fixed weirs with crest elevation 835.0 ft. The fixed weirs are located one adjacent to the lock chamber and the other adjacent to the right bank abutment.

c. The upper lock approach was dredged to elevation 823.0 ft.

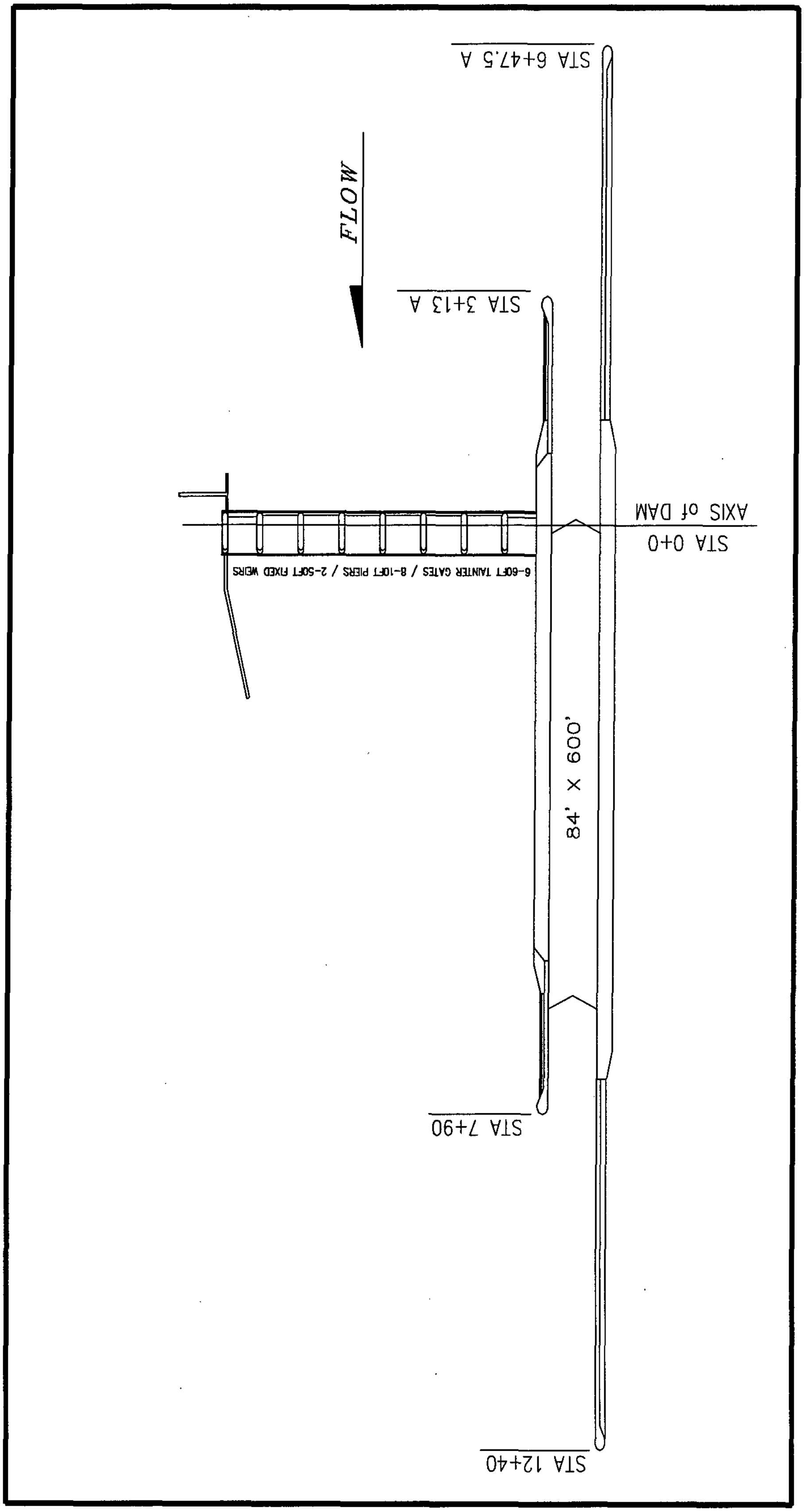


Figure 3. Plan view of Hildebrand Lock and Dam

Results

Water-surface elevations. Water-surface elevations are shown in Table 1. These data indicate that with the controlled riverflows tested, the slope in water-surface in the upper pool (model gauges 1-5) ranged from less than 0.1 ft/mile with a riverflow of 5,000 cfs to about 0.9 ft/mile with a riverflow of 60,000 cfs. With the open riverflows tested, the slope in water surface (model gauges 1-5) ranged from about 1.5 ft/mile with a riverflow of 90,000 cfs to about 2.0 ft/mile with a riverflow of 120,000 cfs.

Current direction and velocities. Current direction and velocity data are shown on Plates 1 - 14. With the controlled riverflows tested, riverflows up to 60,000 cfs, the maximum current magnitudes recorded through the right-hand bend ranged from about 1.8 fps with a riverflow of 10,000 cfs to about 10.4 fps with a riverflow of 60,000 cfs. In the crossing between the bends, the maximum current magnitudes tended to be along the left descending bank and ranged from about 1.7 fps with a riverflow of 10,000 cfs to about 10.6 fps with a riverflow of 60,000 cfs. Through the left-hand bend, the maximum current magnitudes recorded ranged from about 1.7 fps to 9.7 fps with riverflows of 10,000 cfs and 60,000 cfs, respectively. Current magnitudes in the vicinity of the dredged area ranged from less than 0.5 fps with a riverflow of 10,000 cfs to about 4.0 fps with a riverflow of 60,000 cfs.

With the open riverflow conditions tested, maximum current magnitudes through the right-hand bend ranged in magnitude from about 13.0 fps to 15.8 fps with riverflows of 90,000 cfs and 120,000 cfs, respectively. In the crossing between the bends, maximum current magnitudes ranged from 14.6 fps with a riverflow of 90,000 cfs to about 15.5 fps with a riverflow of 120,000 cfs. Maximum current magnitudes through the left-hand bend ranged from about 13.8 fps to 15.3 fps with riverflows of 90,000 and 120,000 cfs, respectively. In the vicinity of the dredged area, current magnitudes ranged from about 5.1 fps with a riverflow of 90,000 cfs to about 6.4 fps with a riverflow of 120,000 cfs.

Navigation conditions, upper lock approach. Navigation conditions entering and leaving the upper lock approach were evaluated using two scenarios. The first scenario assumes that the upper lock approach was dredged such that tows would not run aground. The second scenario assumes that deposition had occurred in the upper lock approach and tows would steer clear of the area.

Downbound tows. Plates 15-19 show navigation conditions for downbound tows approaching the lock along the left descending bank in the vicinity of the dredge area (the first scenario). Navigation conditions for downbound tows entering the upper lock approach were satisfactory with riverflows up through about 20,000 cfs. With a riverflow of 40,000 cfs, navigation conditions were marginally acceptable. With riverflows up through 20,000 cfs, downbound tows could align with and pass through the right-hand bend, make a crossing toward the left bank, and drive or flank the left-hand bend upstream of the lock with very little difficulty. However, once aligned with the lock chamber, downbound tows were required to drive the tow toward the landside guide wall to maintain alignment with and enter the lock chamber (Plates 15-18). The difficulties in maintaining alignment with and entering the lock chamber are associated with the crosscurrent in the upper lock approach in the vicinity of the lock. In some instances, depending on the river discharge or the pilot's judgement, downbound tows may require assistance to enter the lock chamber, i.e. helper boats, smaller tow sizes, or catching a line on the guide wall. With riverflows of 20,000 cfs and above, downbound tows would more than likely flank the bend upstream of the lock, align with the lock chamber about two tow lengths upstream of the guide wall, drive the tow to the landside guide wall, catch a line on the head of the tow to align with, and enter the lock chamber (Plates 18 and 19).

Upbound tows. Navigation conditions for upbound tows leaving the lock along the left descending bank in the vicinity of the dredged area (the first scenario) are shown on Plates 20-24. Navigation conditions for upbound tows leaving the upper lock approach were satisfactory for all riverflows tested. Upbound tows could push out of the lock chamber, align with the flow, and proceed upstream with no significant difficulties. However, the crosscurrent in the upper lock approach in the vicinity of the lock was observed to have a tendency to push the tow riverward and was more noticeable as the river discharge increased.

Downbound tows. Plates 25-27 show navigation conditions for downbound tows approaching the lock and steering clear of the deposition area in the upper lock approach (the second scenario). Navigation conditions were satisfactory with all riverflows tested up through 20,000 cfs. Downbound tows could approach the lock from near the right descending bank, drive across the river channel toward the upstream end of the guide wall, and align with and enter the lock chamber with no significant difficulties for riverflows up to about 10,000 cfs (Plates 25 and 26). However, with a riverflow of 20,000 cfs (Plate 27), downbound tows may require some assistance in maintaining alignment with the lock chamber.

Upbound tows. Navigation conditions for upbound tows leaving the lock and steering clear of the deposition area in the upper lock approach (the second scenario) are shown on Plates 28-30. Navigation conditions for upbound tows leaving the upper lock approach were satisfactory for all riverflows tested. Upbound tows could push out of the lock chamber toward the right descending bank, align with the flow, and proceed upstream with no significant difficulties.

Plan A

Description

The primary objective in the development of Plan A was to increase velocities in the upper lock approach above the threshold velocity for deposition; and at the same time, ensure that the implemented plan did not have any significant adverse impacts on navigation. As described previously, several intermediate tests were performed on the model which led to the development of Plan A. Plan A is shown in Figure 4 and is the same as base tests with existing conditions with one exception: Three submerged dikes were placed along the right descending bank in the vicinity of the dredged area. Information about these dikes can be found in Table 2.

Results

Water-surface elevations. Water-surface elevations are shown in Table 3. These data indicate that with the controlled riverflows tested, the slope in water surface in the upper pool (model gauges 1-5) ranged from less than 0.1 ft/mile with a riverflow of 10,000 cfs to about 1.0 ft/mile with a riverflow of 60,000 cfs. With the open riverflows tested, the slope in water surface (model gauges 1-5) ranged from about 1.6 ft/mile with a riverflow of 90,000 cfs to about 2.0 ft/mile with a riverflow of 120,000 cfs. With the open riverflows, water-surface elevations in the upper pool were increased when compared to base tests by about 0.3 ft.

Current direction and velocities. Current direction and velocity data were collected for riverflows up through 40,000 cfs and are shown in Plates 31 - 38. With all controlled riverflows tested, there were no significant changes in current magnitudes or patterns observed in the crossing between the bends when compared to base tests with existing conditions. However, the flow pattern in the upper lock approach in the dredged area was generally parallel to the left bank to a point just upstream of the riverward guard wall where the flow moves across the approach and over the dam. Current magnitudes in the upper lock approach in the dredged area were increased when compared to base tests with existing conditions. On the average, current magnitudes in the upper lock approach were increased anywhere from 0.2 to 0.6 fps when compared to base tests with existing conditions. This was desired to increase the sediment-carrying capacity of the flow and reduce shoaling in the upper lock approach.

Navigation conditions, upper lock approach. Navigation conditions entering and leaving the upper lock approach were evaluated in the same manner as base tests with existing conditions.

Downbound tows. Plates 39-44 show navigation conditions for downbound tows approaching the lock along the left descending bank in the vicinity of the dredged area (the first scenario). Navigation conditions for downbound tows entering the upper lock approach were satisfactory with all riverflows tested, but not without some difficulties. For riverflows up through 20,000 cfs (99.85 percent of all lockages at this discharge or less), downbound tows could drive or flank the left-hand bend upstream of the lock, align with, and drive the head of the tow to the landside guide wall, where a line could be caught on the head of the tow if needed to enter the lock chamber. Plates 40 and 42 show downbound tows flanking the bend, where Plates 39, 41, and 43 show downbound tows driving the bend upstream of the lock. With a riverflow of 40,000 cfs (Plate 44), downbound tows were required to flank the bend to get aligned with the lock

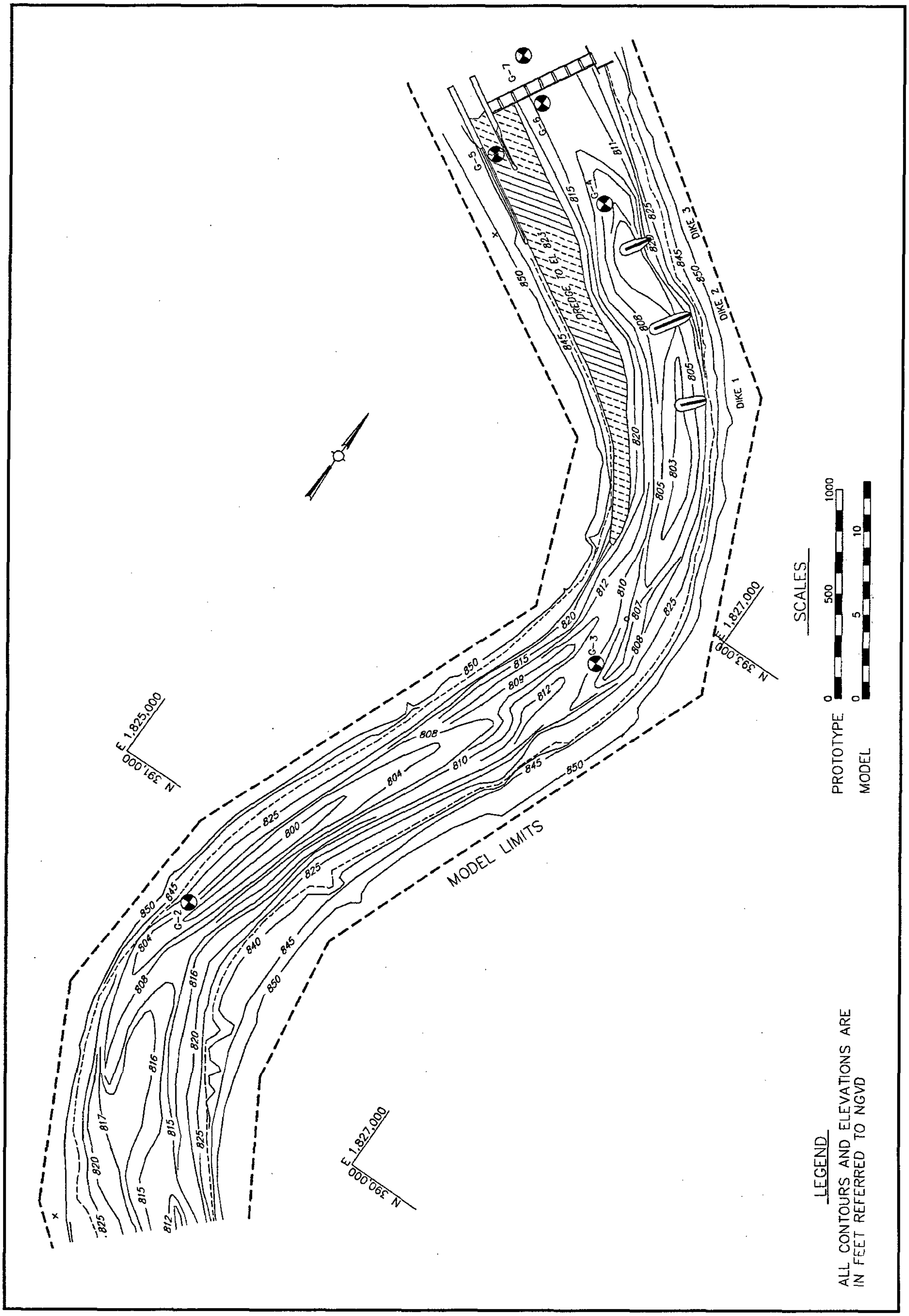


Figure 4. Plan A

chamber. It should be noted that by increasing current magnitudes in the upper lock approach to reduce deposition tendencies, the crosscurrent (outdraft) upstream of the riverward guard wall was increased. By increasing the crosscurrent, maintaining alignment with the lock chamber when close to the lock is more difficult than those observed with base tests. Depending on pilot judgement, some assistance in maintaining alignment with the lock chamber may be required, particularly with riverflows of 20,000 cfs and above (0.15 percent of all lockages at this discharge or above).

Upbound tows. Navigation conditions for upbound tows leaving the lock along the left descending bank in the vicinity of the dredge area (the first scenario) are shown in Plates 45-48. Navigation conditions for upbound tows leaving the upper lock approach were satisfactory for all riverflows tested. However, it should be noted that the crosscurrent in the upper lock approach upstream of the riverward guard wall in the vicinity of the lock was observed to be about twice as strong as that observed with base tests with existing conditions.

Downbound tows. Plates 49-51 show navigation conditions for downbound tows approaching the lock and steering clear of the deposition area in the upper lock approach (the second scenario). In general, navigation conditions for downbound tows approaching the lock were more difficult than those observed with base tests due to the increased amount of flow in the upper lock approach. The crosscurrent in the immediate vicinity of the lock was increased with the implemented plan; thereby making it more difficult for downbound tows to maintain alignment with the lock chamber. This tendency was most noticeable as the river discharge increased to 10,000 cfs and above (Plates 50 and 51). Less than 12 percent of all lockages occur at 10,000 cfs and above.

Upbound tows. Navigation conditions for upbound tows leaving the lock and steering clear of the deposition area in the upper lock approach (the second scenario) are shown on Plates 52-54. Navigation conditions were satisfactory for all riverflows tested. Upbound tows could push out of the lock chamber toward the right descending bank, align with the flow, and proceed upstream with no significant difficulties.

4 Numerical Model

Model Description

The two-dimensional (2-D) numerical model study was conducted using the TABS-2 modeling system.[1] This system provides 2-D solutions to open-channel and sediment problems using finite element techniques. The system consists of more than 40 computer programs to perform modeling and related tasks. A 2-D depth-averaged hydrodynamic numerical model, RMA-2V, was used to generate the flow field. The flow field was then used with the sediment properties of the river as input to a 2-D sedimentation model, STUDH. The other programs in the system perform digitizing, grid generation, data management, graphical display, output analysis, and model interfacing tasks. The sediment model requires hydraulic parameters from RMA-2V, sediment characteristics, inflow concentrations, and sediment diffusion coefficients. The sediment is treated as cohesive, and deposition rates were calculated with the equations of Krone.

The Finite Element Grid

Finite element grids were developed to simulate the Monongahela River from river mile 107.8 downstream to river mile 109.5 at the Hildebrand Lock and Dam, a distance of 1.7 miles. The overall grid was modified to accommodate submerged dike plans only within the dike field. All other areas of the model grid were identical for all testing. Initial bed elevations were obtained from the same hydrographic surveys used for physical model construction. A typical model grid of the entire 1.7-mile reach is shown in Figure 5. The existing condition and plan grids were identical except in the area where the proposed submerged dikes were located. The existing-condition grid in the study area is shown in Figure 6. The plan grid within the study area is shown in Figure 7. The existing condition grid consisted of 2,832 elements and 8,751 nodes, while the plan grid consisted of 2,832 elements and 8,751 nodes.

[1] Thomas, W. A., and McAnally, W. H., Jr. (1985). "User's manual for the generalized computer program system; open-channel flow and sedimentation, TABS-2, main text and Appendices A through O," Instruction Report HL-85-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

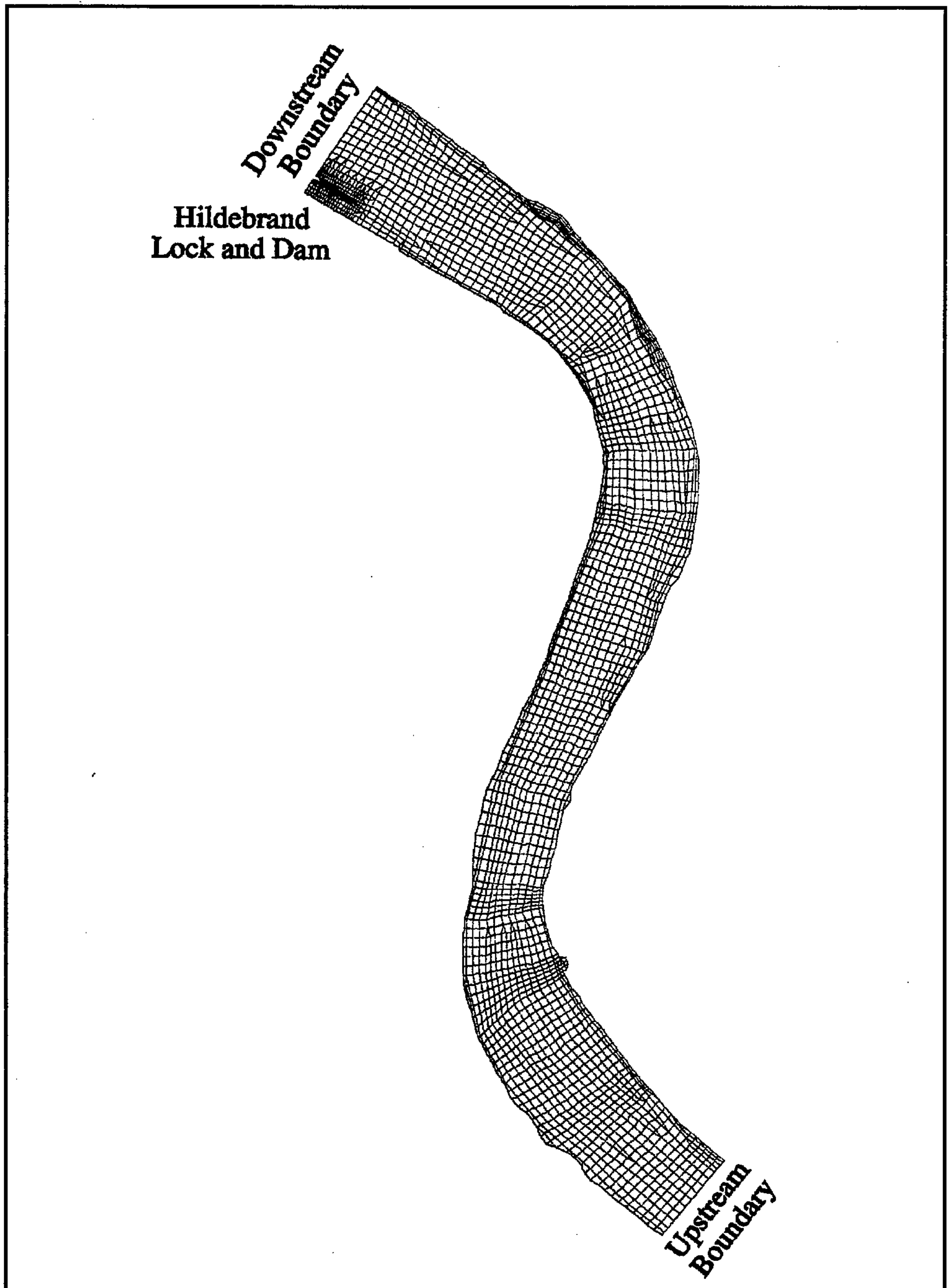


Figure 5. Model grid

Hydrodynamic Boundary Conditions

The model testing included four steady-state hydrodynamic boundary conditions. For each condition, a discharge was specified at the upstream boundary and a water level was specified at the downstream boundary. The

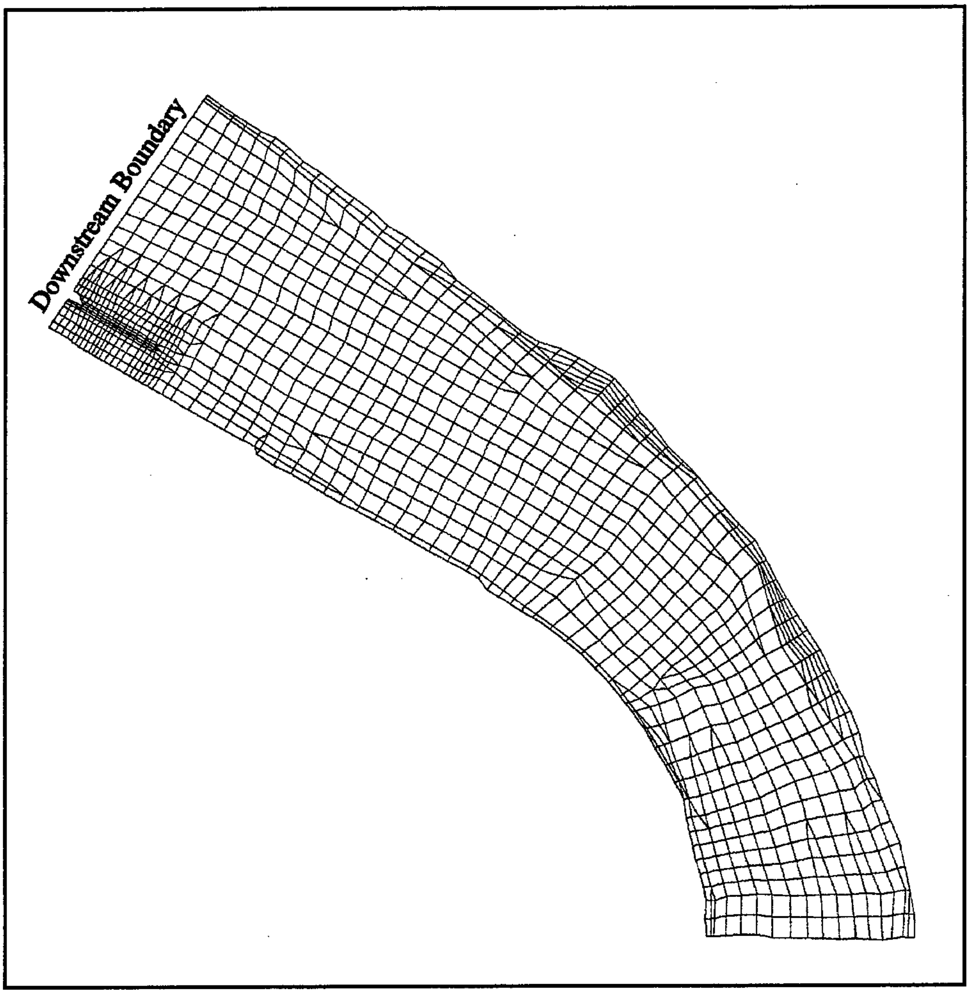


Figure 6. Existing-condition model grid within study area

discharges and stages used and the period of time simulated are given in the following tabulation.

Discharge, cfs	Downstream Elevation, ft	Time, days
5,000	835.0	50
10,000	835.0	30
20,000	835.0	10
40,000	835.0	5

Within the study reach, Manning's n values ranged from 0.025 in the main river channel to 0.10 over the submerged dikes in the plan tests.

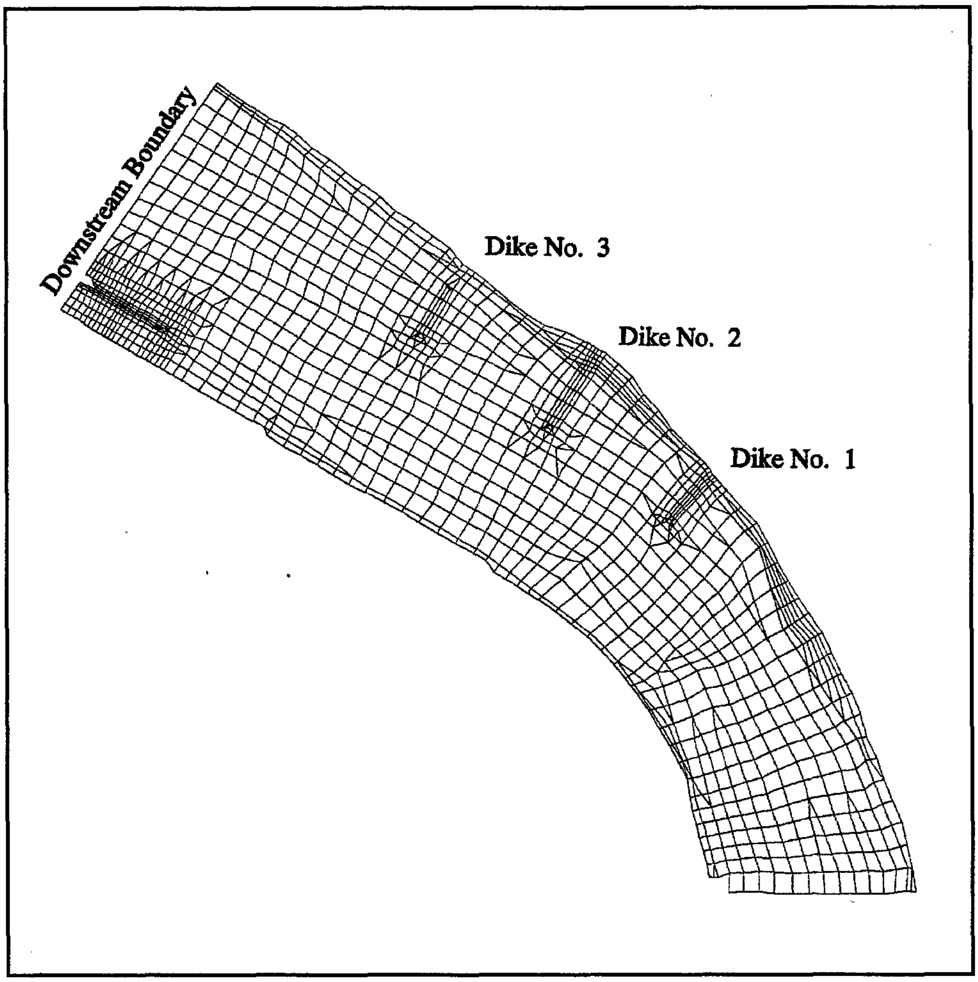


Figure 7. Plan model grid within study area

Sediment Transport Boundary Conditions

The boundary information required by STUDH was suspended sediment concentrations at the upstream boundary and bed sediments within the model. Primary input parameters required by STUDH were dispersion coefficients, critical shear stresses for deposition and erosion, critical concentrations, and erosion rate constants.

Suspended sediment concentration

Suspended sediment concentrations used at the upstream boundary were generated from sediment rating information received from the Pittsburgh District Office as tabulated below:

Water Discharge, CFS	Sediment Load, tons/day	Sediment Concentration, kg/m^3
5,000	350	0.026
10,000	1,620	0.060
13,600	5,680	0.105
20,000	20,750	0.192

Critical shear stresses

Based on the sediment sample analysis conducted at WES, the critical shear stress for deposition used in the model was 0.08 Pa (n/m^2) and the critical shear stress for erosion used in the model was 0.50 Pa (n/m^2). The particle settling velocity was estimated to be 0.00012 m/sec.

Model Adjustment

Hydrodynamic adjustment

Because of the limited prototype velocity data, the adjustment procedure was based on comparison to the physical model's water level and velocity distribution results for discharges of 5,000 cfs, 10,000 cfs, 20,000 cfs, and 40,000 cfs.

The primary adjustment parameters required by the hydrodynamic code as model input were Manning's n values and turbulent exchange coefficients. These parameters were adjusted within reasonable limits until velocity distribution in the study reach agreed with observations in the physical model for each discharge tested.

Flow fields generated by the numerical model appeared reasonable. Examples of existing-condition and plan velocity patterns for the 10,000-cfs discharge are shown in Figures 8 and 9, respectively. The results can be compared with Plates 1 and 2 and 31-33, respectively, from the physical model.

Sedimentation adjustment

Sedimentation adjustment was limited by the limited field data for verification. The only available field data consisted of the bed sediment samples in the depositional zone in the lock approach channel. The procedure for setting up the sediment code was based on laboratory measurements of depositional and erosional shear stresses for the bed sediment samples collected onsite. Once the observed sediment parameters were set in the model, the results appeared reasonable for the conditions tested.

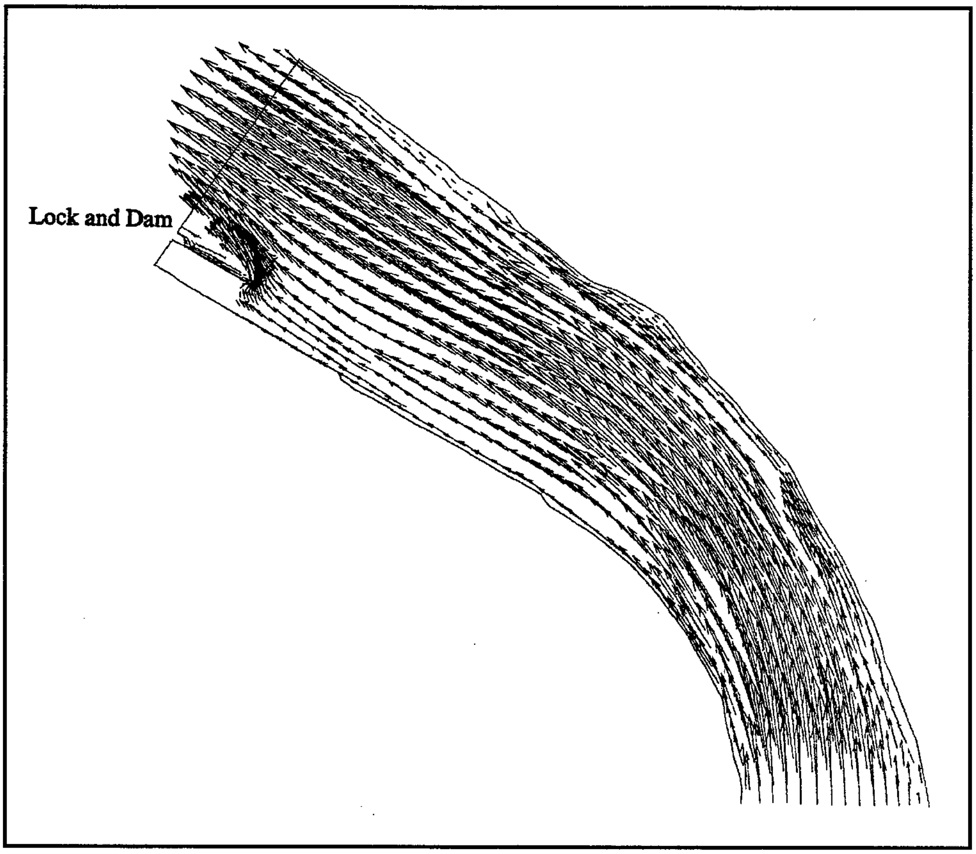


Figure 8. Existing-condition velocity patterns for 10,000-cfs discharge

Tests and Results

The test procedure selected for evaluating existing conditions versus plan was to step through the sediment model using the four steady-state discharges sequentially. Each test started with 50 days of 5,000-cfs discharge, followed by 30 days of 10,000-cfs discharge, then 10 days of 20,000-cfs discharge, and then finally 5 days of 40,000 cfs discharge.

During testing, it was determined that the 20,000- and 40,000-cfs steps were unnecessary for plan evaluation, since these rare-event discharges were erosional in the approach channel rather than depositional, and the approach channel was excavated in rock and nonerodible.

Existing-condition and Plan A bed-shear-stress patterns for the 5,000-cfs and 10,000-cfs discharges are given in Figures 10 to 13. As demonstrated by these figures, in the vicinity of the lock approach, the plan condition results in significantly increased bed shear stresses over the existing condition, which in turn should result in reduced deposition rates.

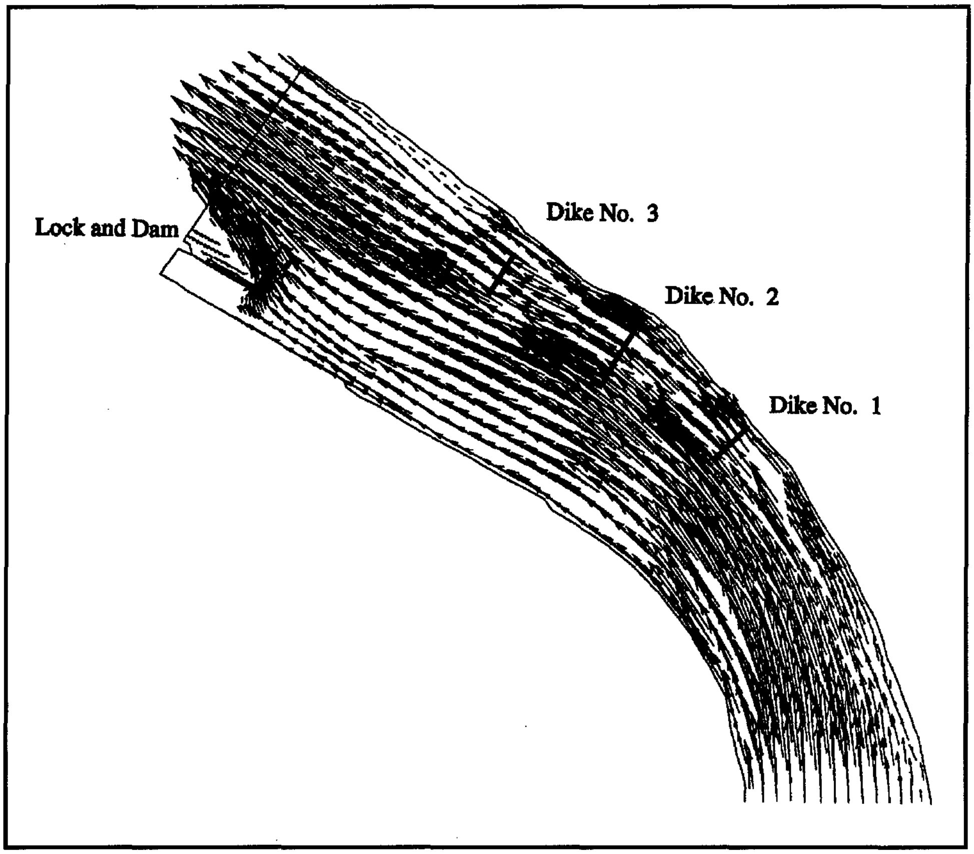


Figure 9. Plan velocity patterns for 10,000-cfs discharge

Accumulated deposition in the vicinity of the lock approach after 50 days of 5,000-cfs discharge followed by 30 days of 10,000-cfs discharge is shown in Figures 14 and 15. As demonstrated by these patterns, the Plan A deposition in the vicinity of the lock approach is only a small fraction (about 20 percent) of that observed under the existing condition. Based on these numerical model results, it is concluded that the proposed dikes will be effective in significantly reducing deposition of fine material in the lock approach.

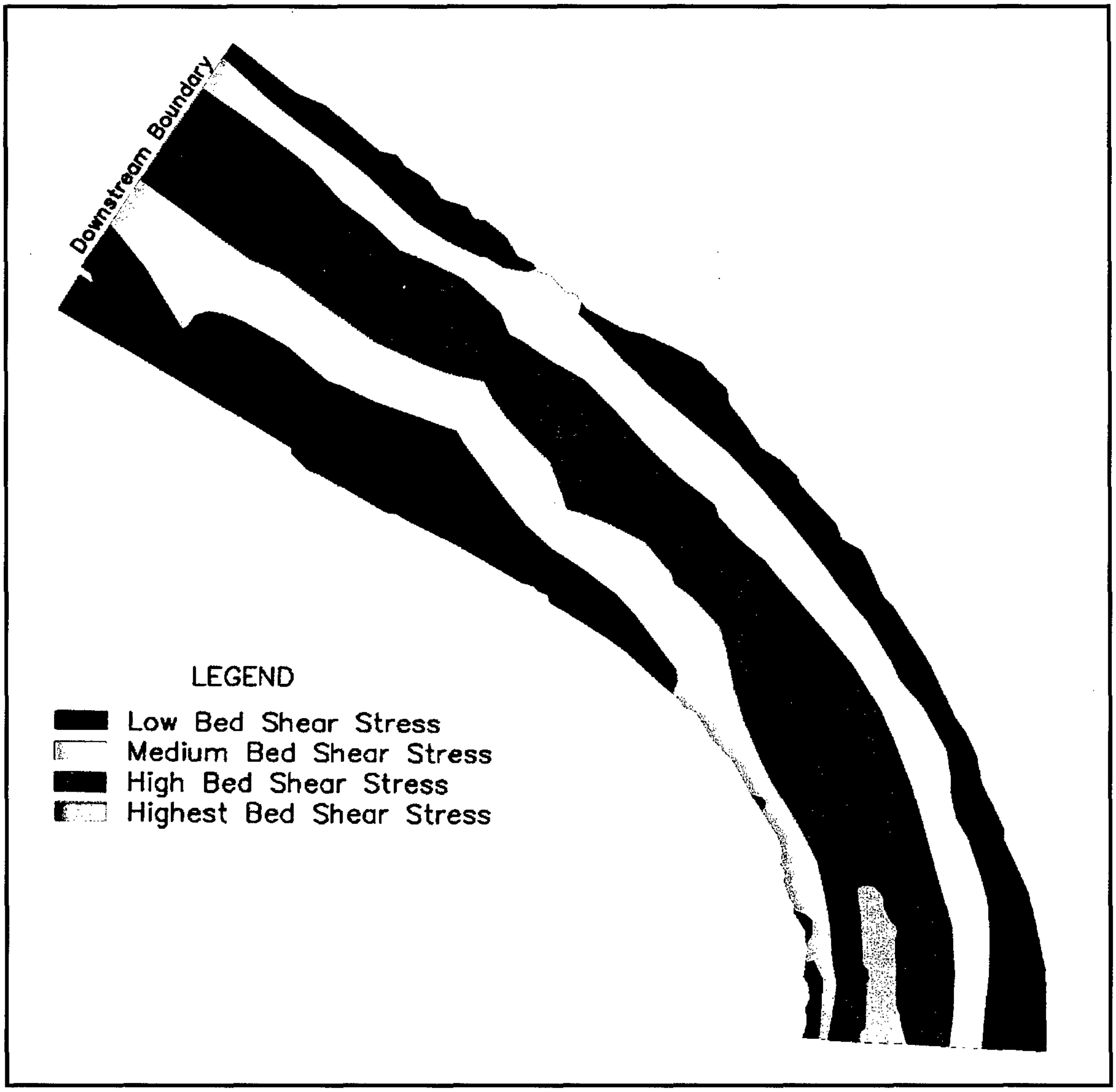


Figure 10. Bed shear stress, existing conditions, discharge = 5,000 cfs

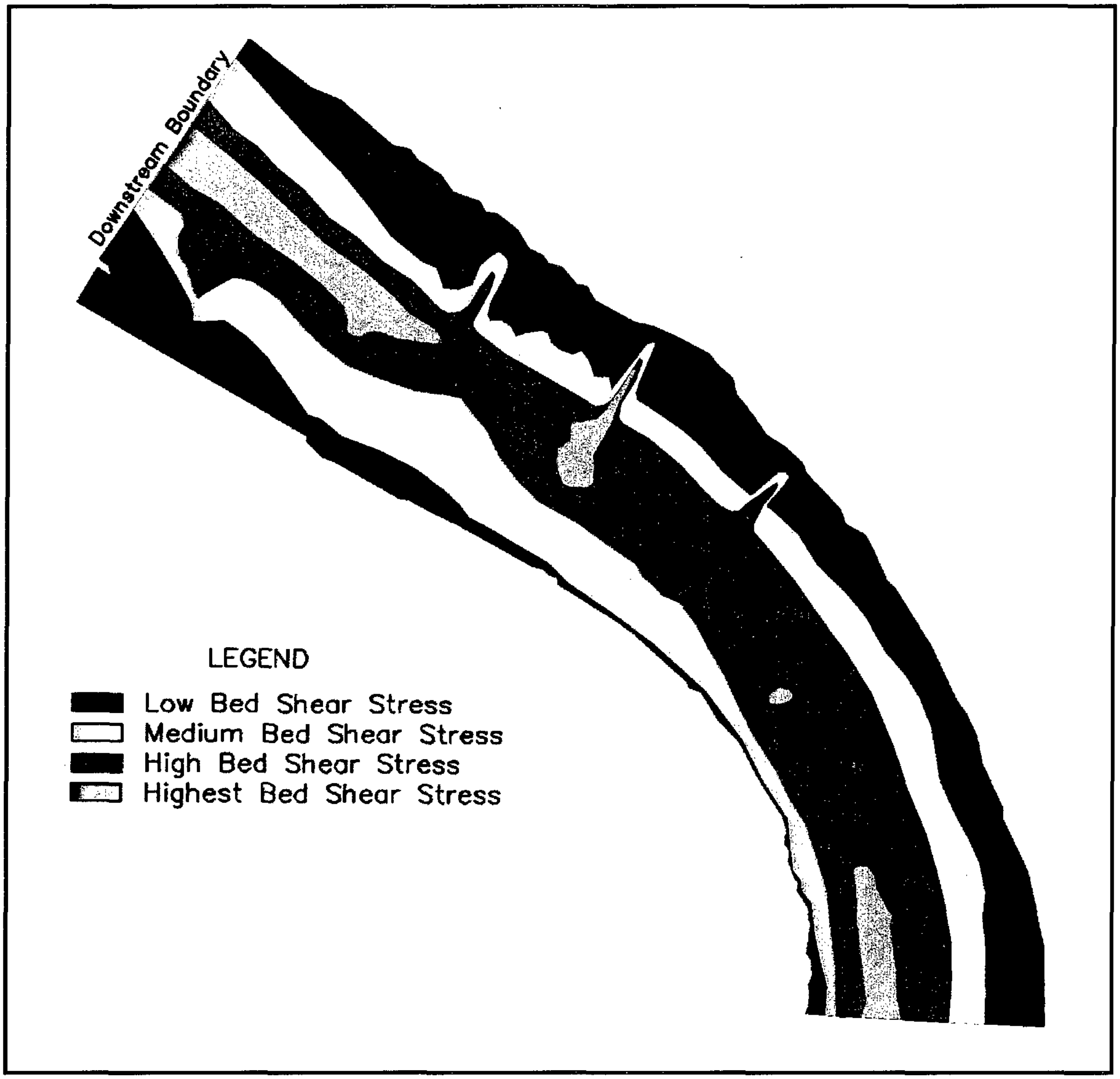


Figure 11. Bed shear stress, plan conditions, discharge = 5,000 cfs

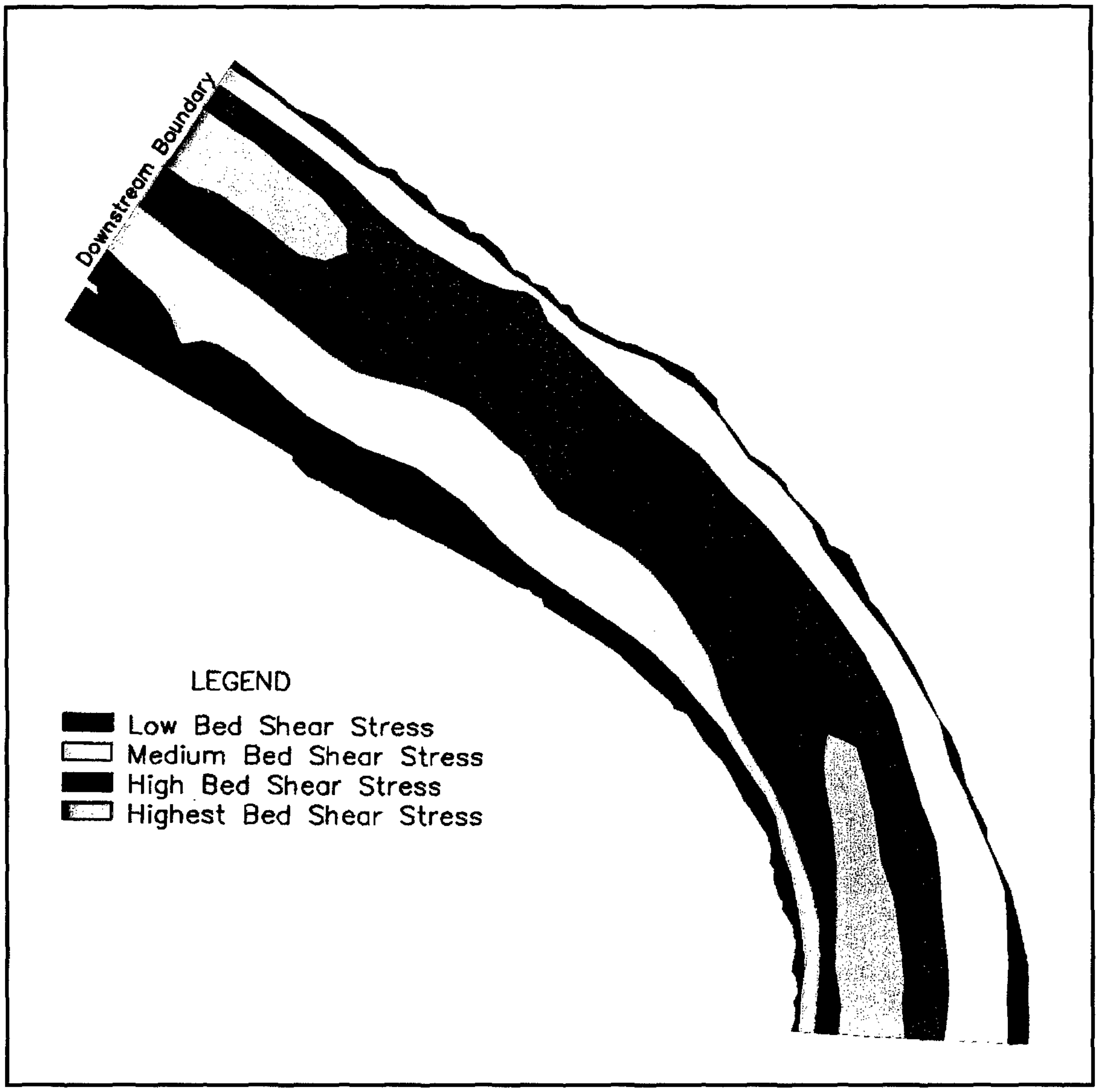


Figure 12. Bed shear stress, existing conditions, discharge = 10,000 cfs

Figure 13. Bed shear stress, plan conditions, discharge = 10,000 cfs

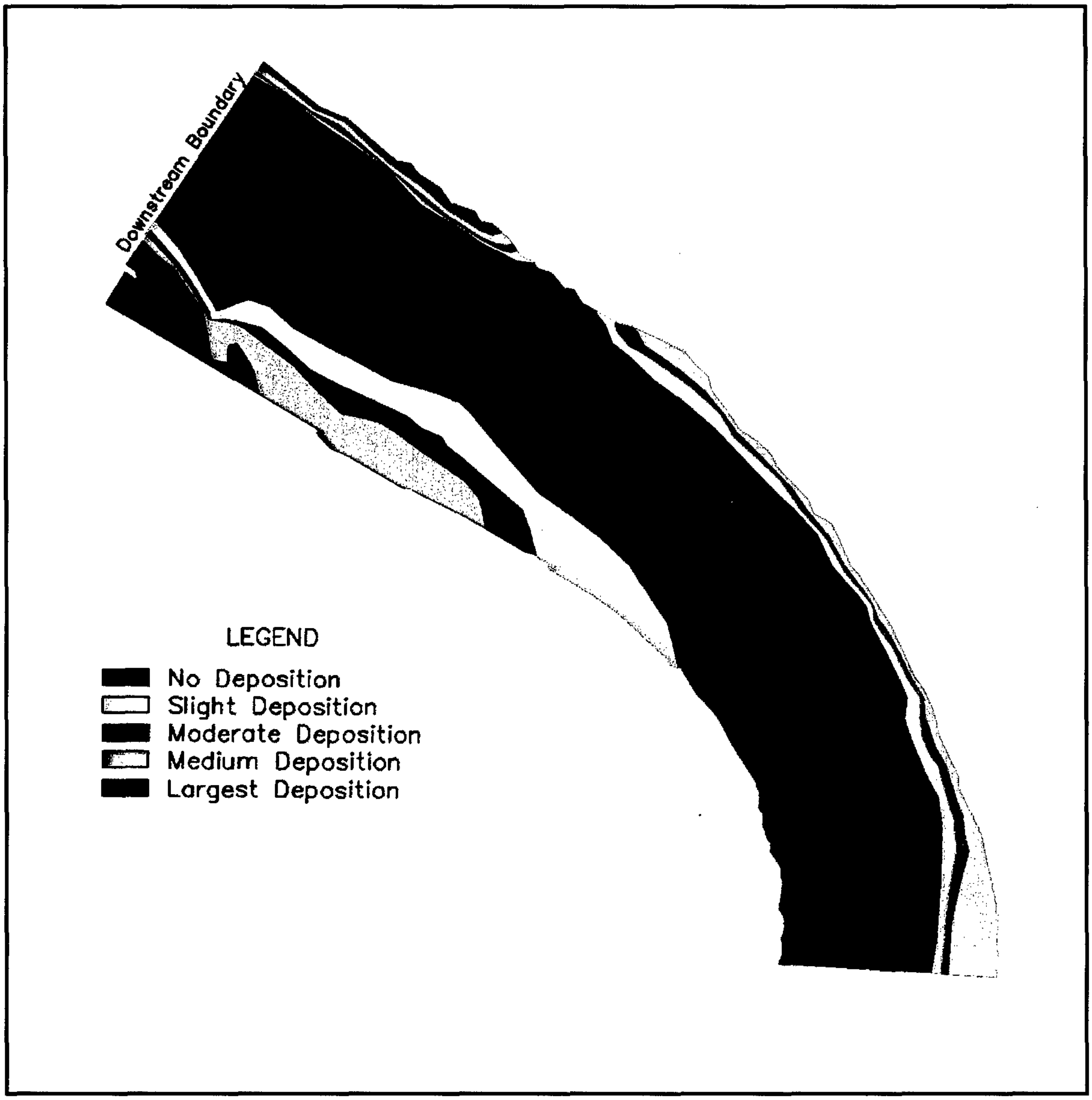


Figure 14. Deposition patterns, existing conditions, 50 days at 5,000 cfs and 30 days at 10,000 cfs

Figure 15. Deposition patterns, plan conditions, 50 days at 5,000 cfs and 30 days at 10,000 cfs

5 Conclusions

Analysis of this investigation's results is based principally on the following: the effects of the implemented plan on water-surface elevations, current directions and velocities, the effects of the resulting currents on the behavior of the model towboat and barges entering and leaving the lock, and the reduction or elimination of sediment in the upper lock approach.

The small scale of the model made it difficult to reproduce accurately the hydraulic characteristics of the prototype structures or to measure water surface elevations with an accuracy greater than $\pm$ 0.1 ft prototype. The model was of the fixed-bed type and was not designed to simulate the movement of sediment in the prototype. Therefore, changes in channel configuration and slopes resulting from changes in the channel bed and banks that might be caused by changes in flow conditions could not be determined in the model.

Base Test

a. Navigation conditions were satisfactory for downbound tows for riverflows up through 20,000 cfs (99.85 percent of all lockages at this discharge or less). Navigation conditions were marginally acceptable for downbound tows with a riverflow of 40,000 cfs. With riverflows of 20,000 cfs and above (0.15 percent of all lockages at this discharge or above), downbound tows would more than likely flank the bend upstream of the lock. A crosscurrent in the upper lock approach caused some difficulties for downbound tows aligning and maintaining alignment with the lock chamber. This was particularly true for the higher riverflows, i.e. 20,000 cfs and above.

b. Navigation conditions were satisfactory for upbound tows with all riverflows tested. The crosscurrent in the upper lock approach was observed to have a tendency to push the tow riverward while exiting the lock.

Plan A

a. The addition of the three submerged dikes along the right descending bank increased water-surface elevations at model gauge 1 from about 0.1 ft with a riverflow of 10,000 cfs to about 0.3 ft with a riverflow of 120,000 cfs when compared to base tests.

b. The addition of the three submerged dikes along the right descending bank increased current magnitudes in the upper lock approach in the range of 0.2 to 0.6 fps when compared to base tests. This was desired to increase sediment carrying capacity and reduce shoaling in the upper lock approach.

c. Navigation conditions for downbound tows entering the upper lock approach were satisfactory for all riverflows tested, but not without some difficulties. The increased flow in the upper lock approach made aligning with and maintaining alignment with the lock chamber more difficult due to an increase in the crosscurrent magnitudes in the immediate vicinity of the lock. This was most noticeable with a riverflow of 20,000 cfs (99.85 percent of all lockages at this discharge or less).

d. Navigation conditions were satisfactory for upbound tows with all riverflows tested. However, it should be noted that the crosscurrent in the upper lock approach was observed to be stronger than conditions observed with base tests.

Table 1 Base Tests Water-Surface Elevations (ft, NGVD)								
Gauge No.	Discharge in 1,000 cfs							
	5	10	13.6	20	40	60	90	120
1	835.0	835.0	835.1	835.2	835.6	836.2	837.1	840.2
2	835.0	835.0	835.1	835.1	835.3	835.6	836.0	838.9
3	835.0	835.0	835.0	835.0	835.2	835.3	835.6	838.3
4	835.0	835.0	835.0	835.0	835.1	835.0	835.0	837.5
5[1]	835.0	835.0	835.0	835.0	835.0	835.0	835.0	837.4
6	835.0	835.0	835.0	835.0	834.9	834.8	834.7	836.8
Slope (ft/ml)	< 0.1	< 0.1	< 0.1	0.15	0.45	0.85	1.50	2.05

[1] Controlled elevations.

Table 2 Dike Locations, Plan A					
	Stream End of Dike				
Dike No.	Northing	Easting	Azimuth	Approx. Length	Top Elevation
1	393,849	1,826,182	43^0 20' 09"	120 ft	820.0
2	394,072	1,825,871	32^0 24' 44"	185 ft	820.0
3	394,296	1,825,544	30^0 48' 04"	130 ft	820

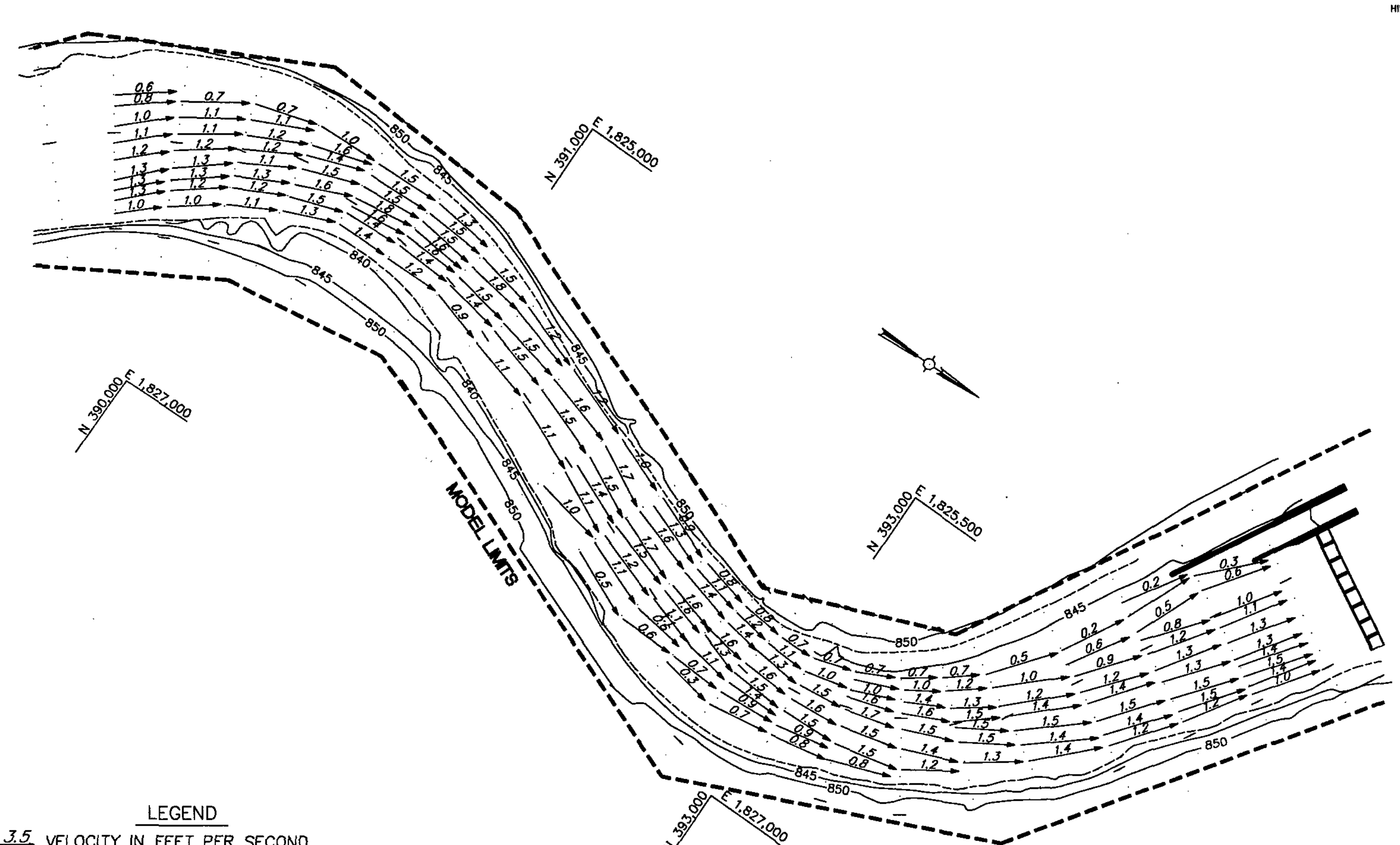
Table 3
Plan A
Water-Surface Elevations (ft, NGVD)

Gauge No.	Discharge in 1,000 cfs							
	5	10	13.6	20	40	60	90	120
1	835.0	835.0	835.1	835.2	835.6	836.3	837.4	840.5
2	835.0	835.0	835.1	835.1	835.3	835.7	836.3	839.2
3	835.0	835.0	835.0	835.0	835.2	835.4	835.9	838.6
4	835.0	835.0	835.0	835.0	835.1	835.0	835.2	837.8
5[1]	835.0	835.0	835.0	835.0	835.0	835.0	835.2	837.7
6	835.0	835.0	835.0	835.0	835.0	834.8	834.8	837.1
SLOPE (ft/ml)	< 0.1	< 0.1	< 0.1	0.15	0.45	0.95	1.60	2.05

[1] Controlled elevations.

NOTE: Base test model setup was maintained,the plan installed, and water-surface elevations were recorded.

HILD-019



LEGEND

3.5 VELOCITY IN FEET PER SECOND

⟶ VELOCITY LESS THAN 0.5 FEET PER SECOND

NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES

PROTOTYPE 0 500 1000

MODEL 0 5 10

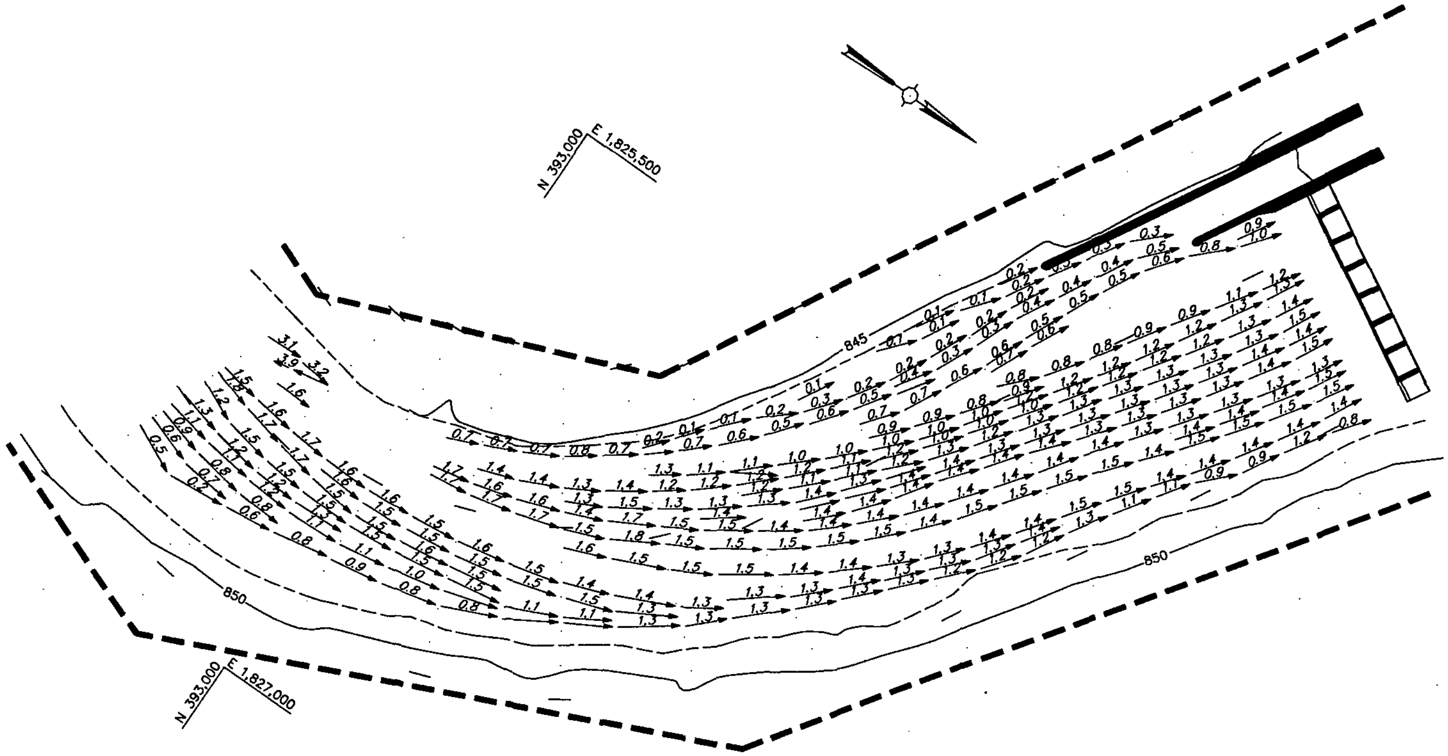
VELOCITIES AND CURRENT DIRECTIONS

BASE TEST

DISCHARGE: 10,000 CFS

UPPER POOL EL: 835.0 FT

HILD-19A



LEGEND

3.5 → VELOCITY IN FEET PER SECOND

—•→ VELOCITY LESS THAN 0.5 FEET PER SECOND

NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES

PROTOTYPE 0 500 1000

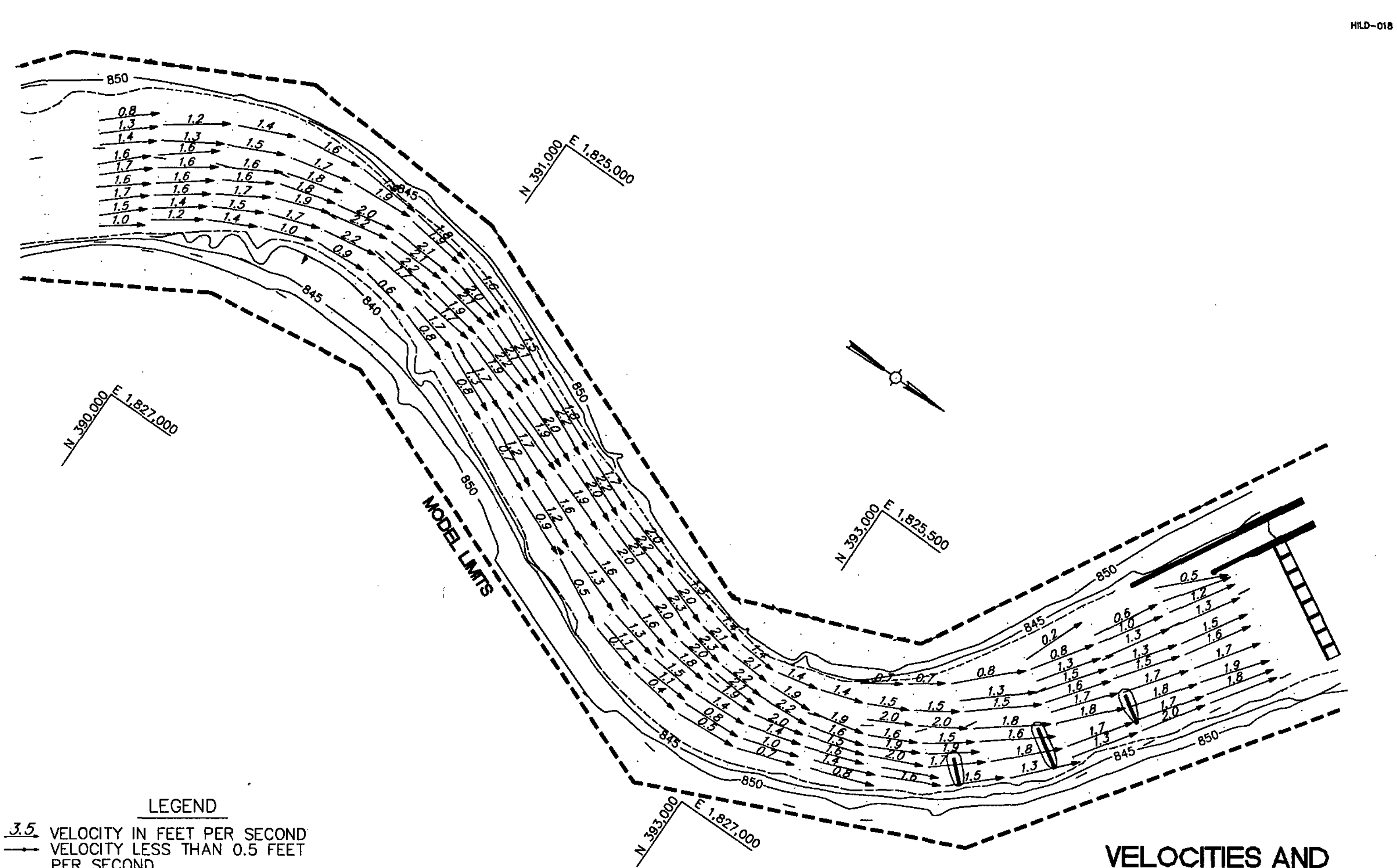
MODEL 0 5 10

VELOCITIES AND CURRENT DIRECTIONS

BASE TEST

DISCHARGE:	10,000	CFS
UPPER POOL EL:	835.0	FT

Plate 2



LEGEND

3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND

NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES

PROTOTYPE 0 500 1000

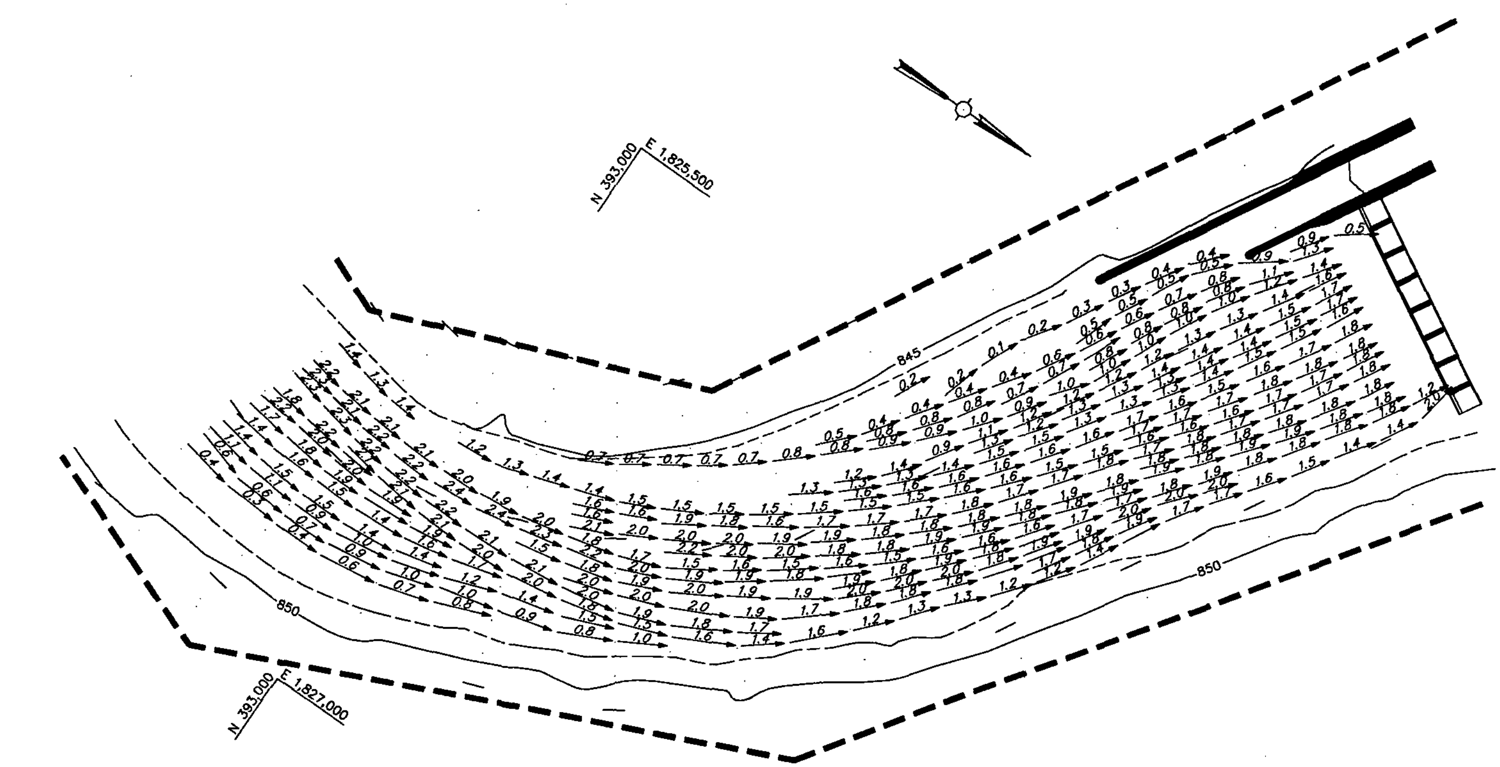
MODEL 0 5 10

VELOCITIES AND CURRENT DIRECTIONS

BASE TEST

DISCHARGE: 13,600 CFS

UPPER POOL EL: 835.0 FT



LEGEND

3.5 VELOCITY IN FEET PER SECOND

VELOCITY LESS THAN 0.5 FEET PER SECOND

NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES

PROTOTYPE 0 500 1000

MODEL 0 5 10

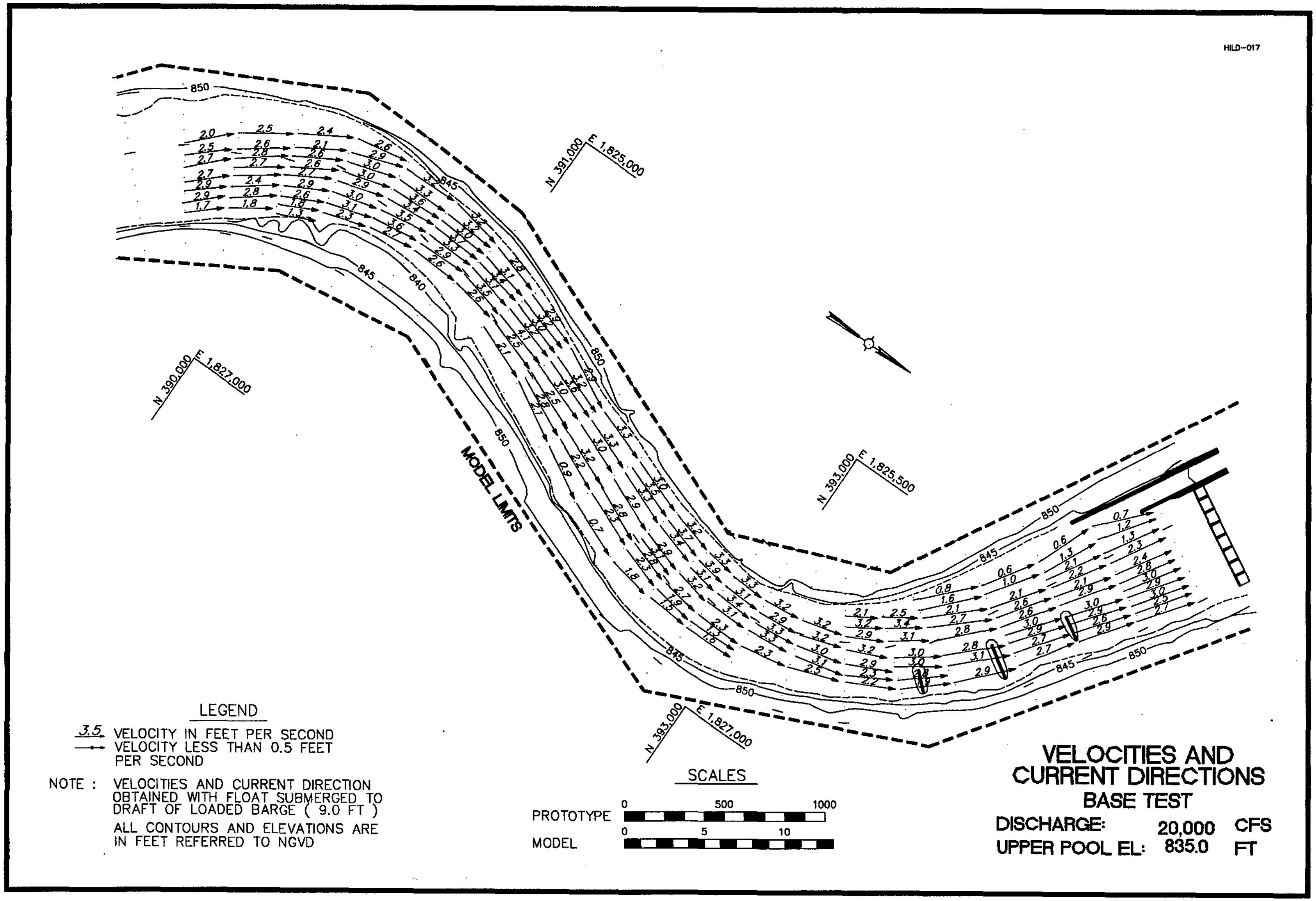
VELOCITIES AND CURRENT DIRECTIONS

BASE TEST

DISCHARGE: 13,600 CFS

UPPER POOL: 835.0 FT

Plate 4


HILD-017
MODEL LIMITS
N 391,000 E 1,825,000
N 390,000 E 1,827,000
N 393,000 E 1,825,500
N 393,000 E 1,827,000
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
SCALES
PROTOTYPE 0 500 1000
MODEL 0 5 10
VELOCITIES AND CURRENT DIRECTIONS
BASE TEST
DISCHARGE: 20,000 CFS
UPPER POOL EL: 835.0 FT

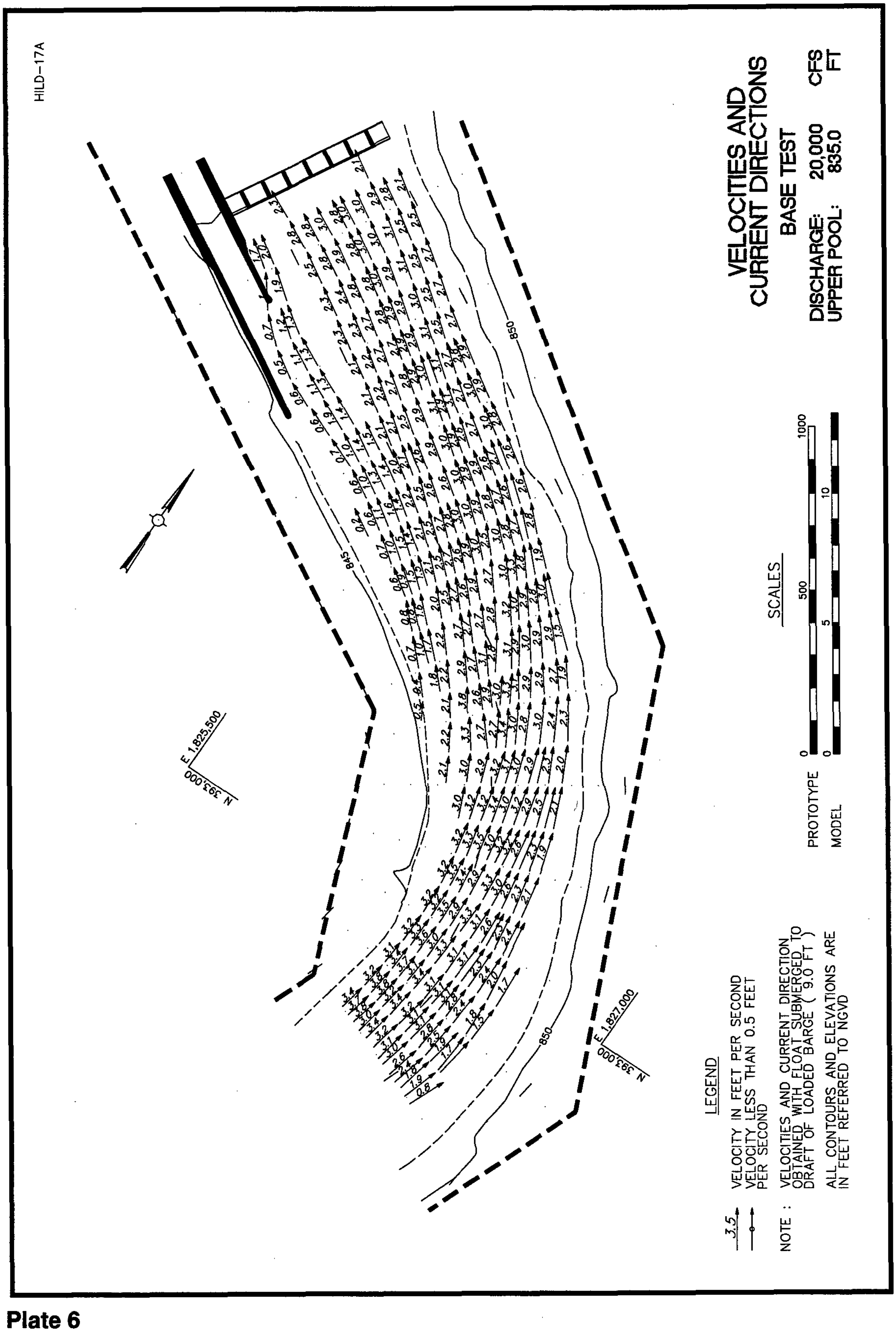
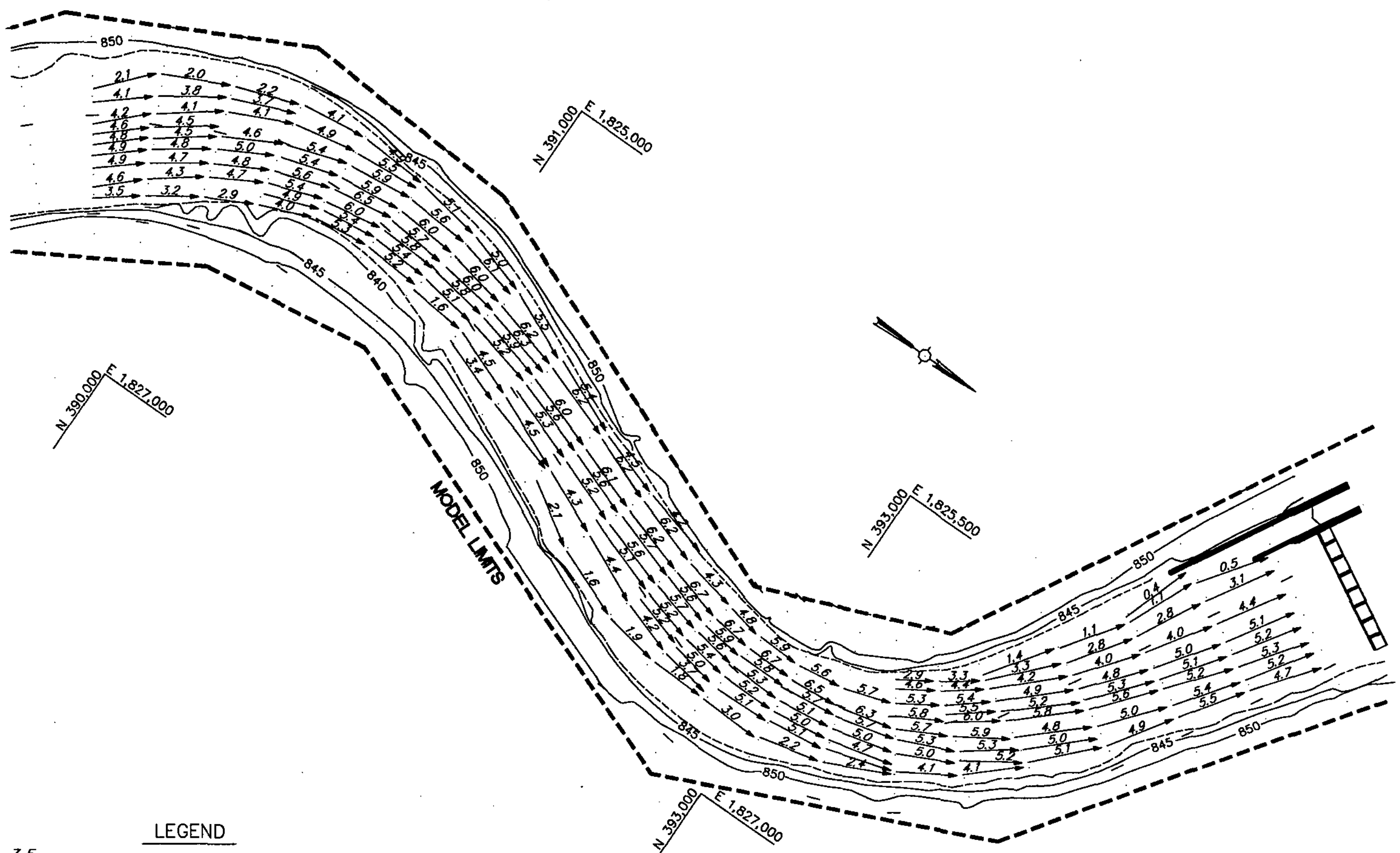

HILD-17A
VELOCITIES AND
CURRENT DIRECTIONS
BASE TEST
DISCHARGE: 20,000 CFS
UPPER POOL: 835.0 FT
SCALES
PROTOTYPE 0 500 1000
MODEL 0 5 10
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
E 1,825,500
N 393,000
E 1,827,000
N 393,000
845
850

Plate 6



LEGEND

3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND

NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES

PROTOTYPE 0 500 1000

MODEL 0 5 10

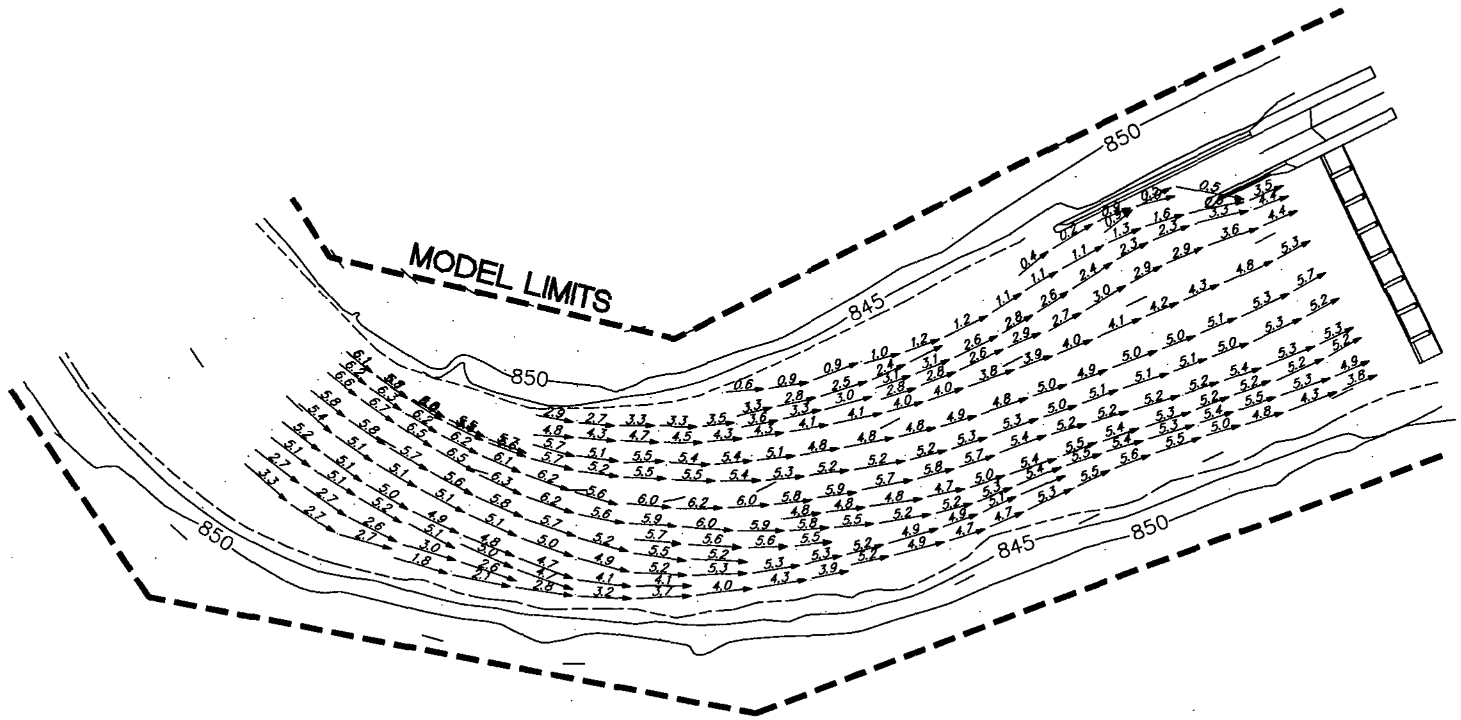
VELOCITIES AND CURRENT DIRECTIONS

BASE TEST

DISCHARGE: 40,000 CFS

UPPER POOL EL: 835.0 FT

HILD-14A



LEGEND

3.5 → VELOCITY IN FEET PER SECOND
—•→ VELOCITY LESS THAN 0.5 FEET PER SECOND

NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)

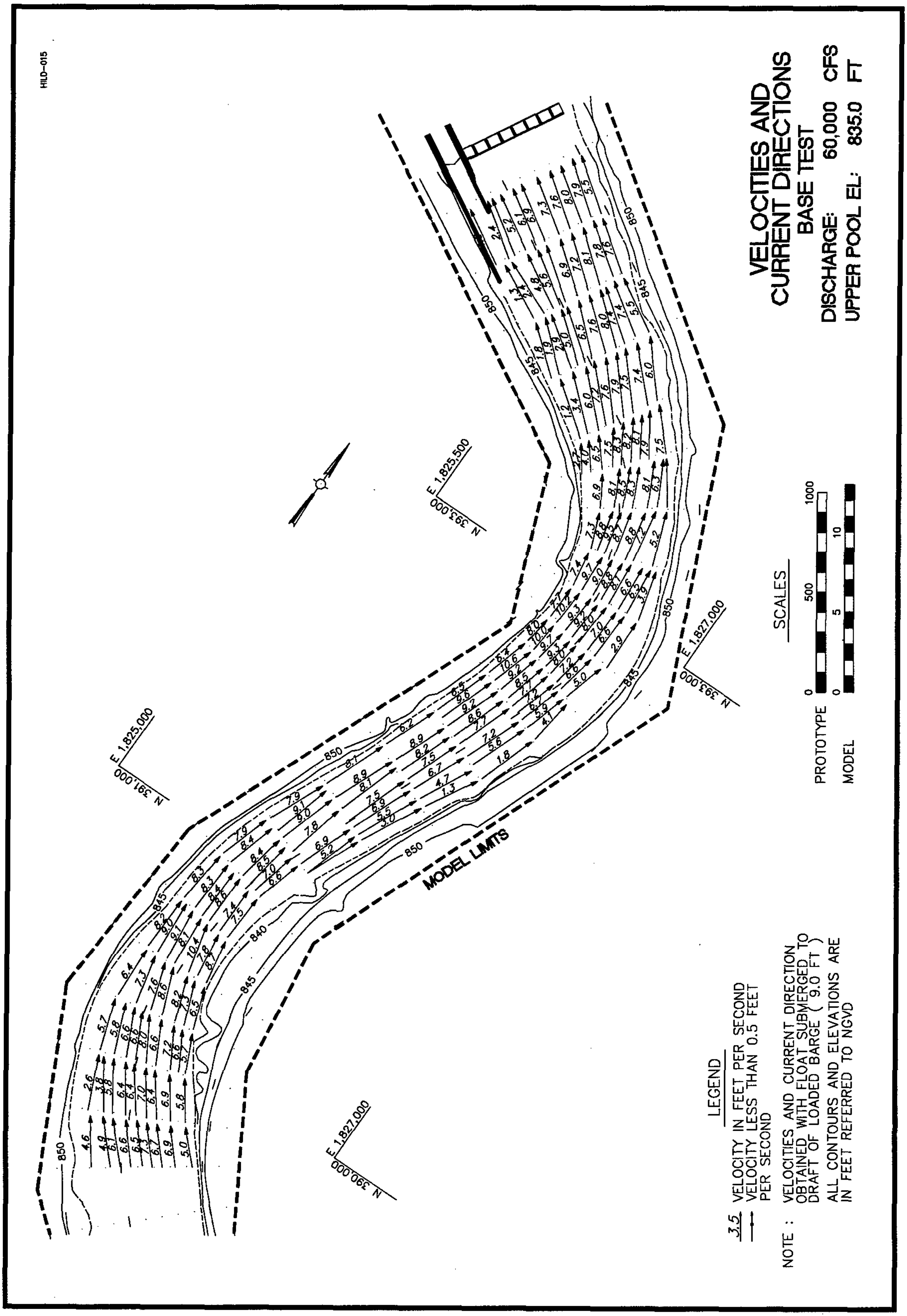
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES

PROTOTYPE 0 500 1000
MODEL 0 5 10

VELOCITIES AND CURRENT DIRECTIONS
BASE TEST

DISCHARGE: 40,000 CFS
UPPER POOL: 835.0 FT


VELOCITIES AND
CURRENT DIRECTIONS
BASE TEST
DISCHARGE: 60,000 CFS
UPPER POOL EL: 835.0 FT
HILD-015
SCALES
PROTOTYPE 0 500 1000
MODEL 0 5 10
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
MODEL LIMITS
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N 393,000
E 1,825,000
N 391,000
E 1,827,000
N 393,000
E 1,827,000
N 390,000

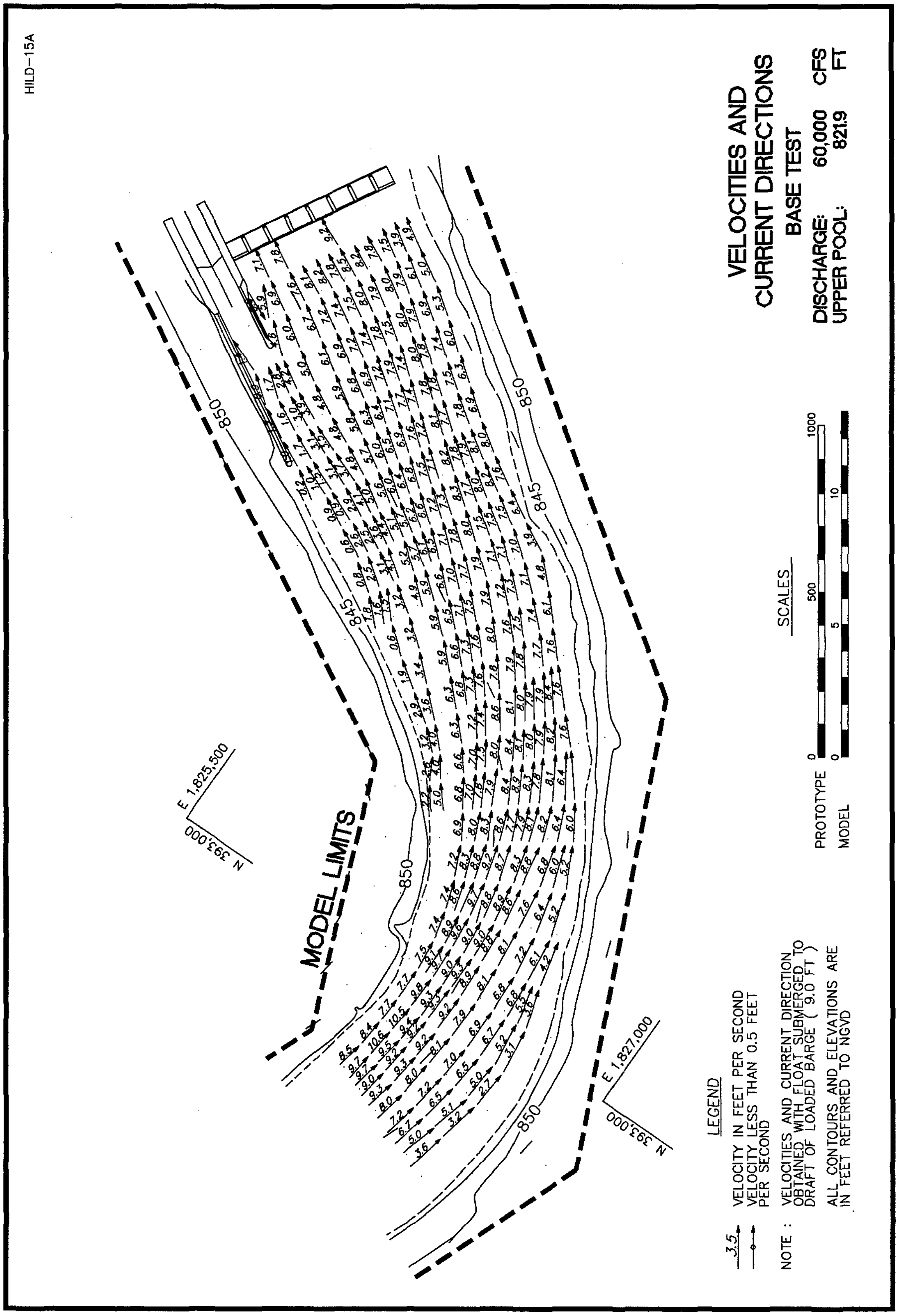
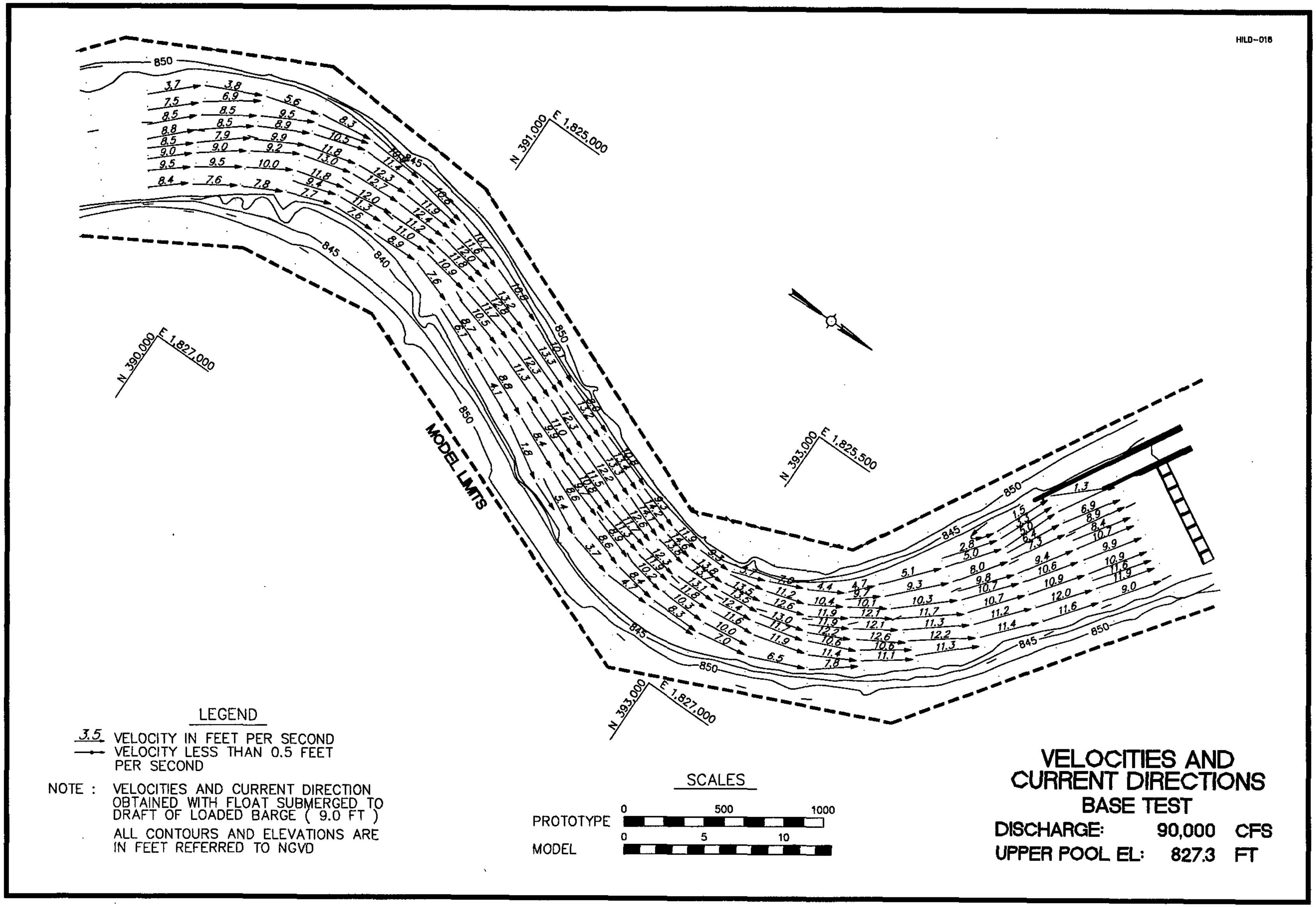

HILD-15A
VELOCITIES AND
CURRENT DIRECTIONS
BASE TEST
DISCHARGE: 60,000 CFS
UPPER POOL: 821.9 FT
MODEL LIMITS
E 1,825,500
N 393,000
E 1,827,000
N 393,000
850
845
SCALES
PROTOTYPE 0 500 1000
MODEL 0 5 10
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

Plate 10



HILD-018
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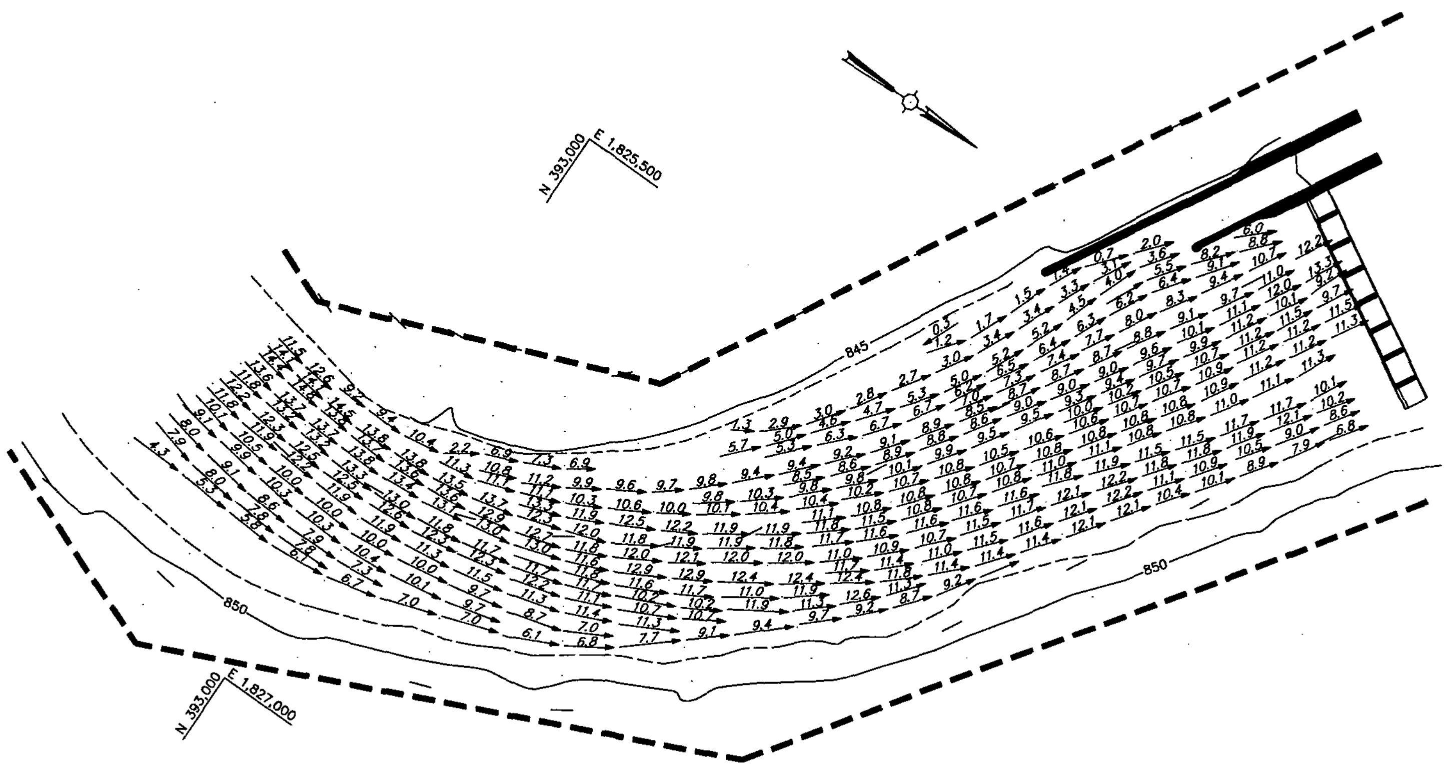
E 1,825,000
N 390,000
E 1,827,000
N 393,000
E 1,825,500
N 393,000
E 1,827,000
MODEL LIMITS
850
845
840
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
SCALES
PROTOTYPE 0 500 1000
MODEL 0 5 10
VELOCITIES AND CURRENT DIRECTIONS
BASE TEST
DISCHARGE: 90,000 CFS
UPPER POOL EL: 827.3 FT

HILD-16A



LEGEND

3.5 → VELOCITY IN FEET PER SECOND

—o→ VELOCITY LESS THAN 0.5 FEET PER SECOND

NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES

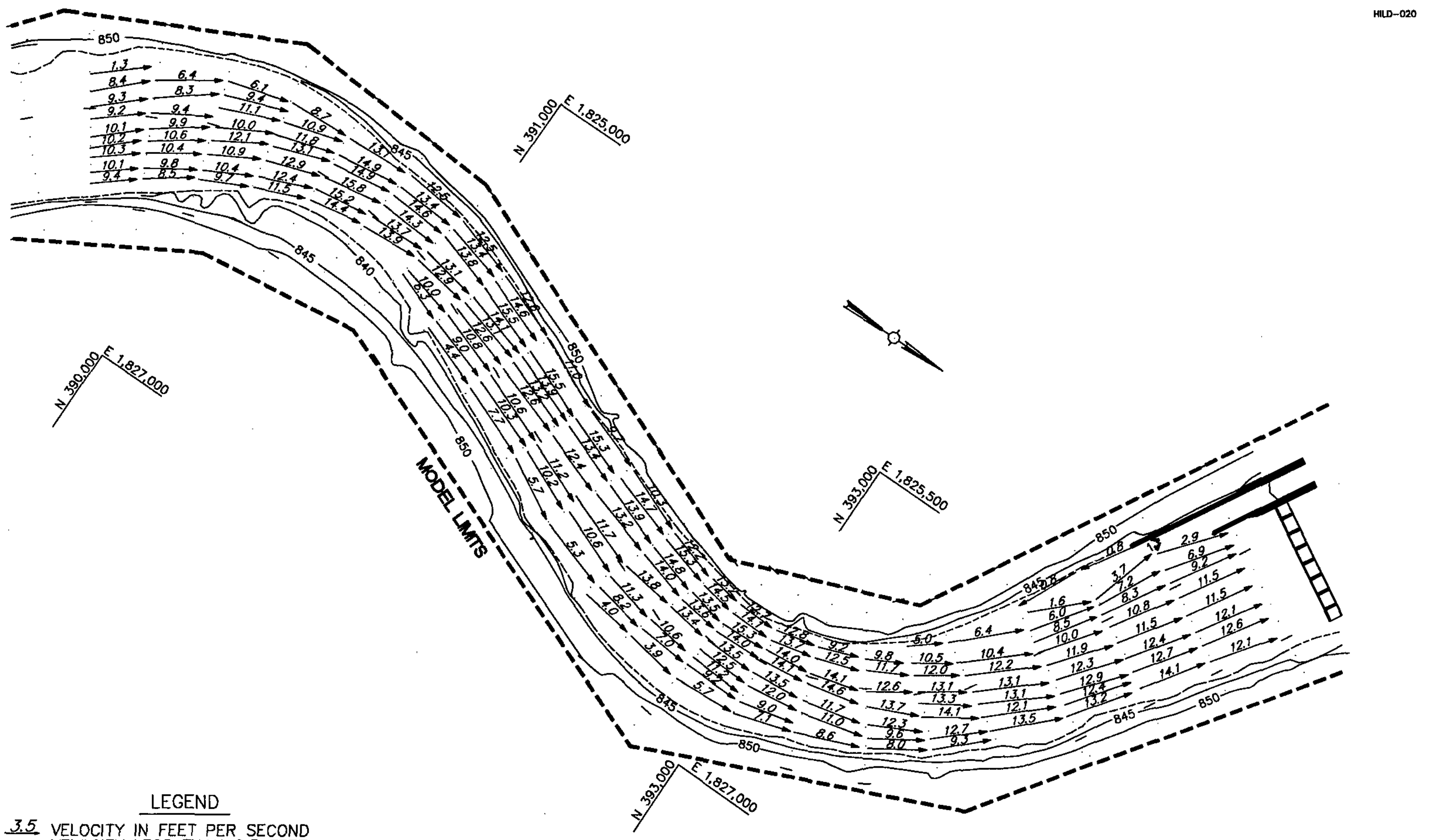
PROTOTYPE 0 500 1000

MODEL 0 5 10

VELOCITIES AND CURRENT DIRECTIONS

BASE TEST

DISCHARGE: 90,000 CFS
UPPER POOL: 827.3 FT



LEGEND

3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND

NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES

PROTOTYPE 0 500 1000

MODEL 0 5 10

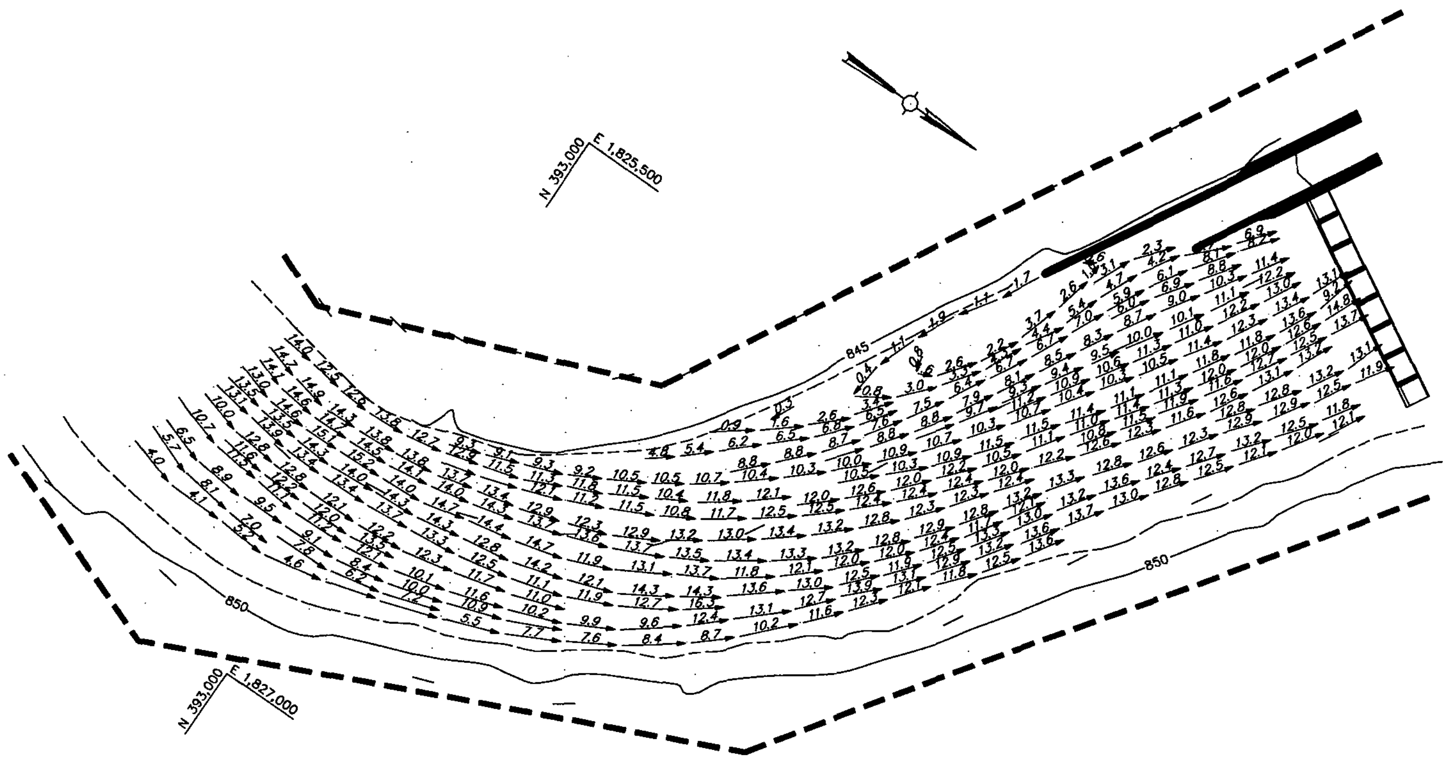
VELOCITIES AND CURRENT DIRECTIONS

BASE TEST

DISCHARGE: 120,000 CFS

UPPER POOL EL: 832.0 FT

HILD-20A



LEGEND

3.5 → VELOCITY IN FEET PER SECOND

—o→ VELOCITY LESS THAN 0.5 FEET PER SECOND

NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES

PROTOTYPE 0 500 1000

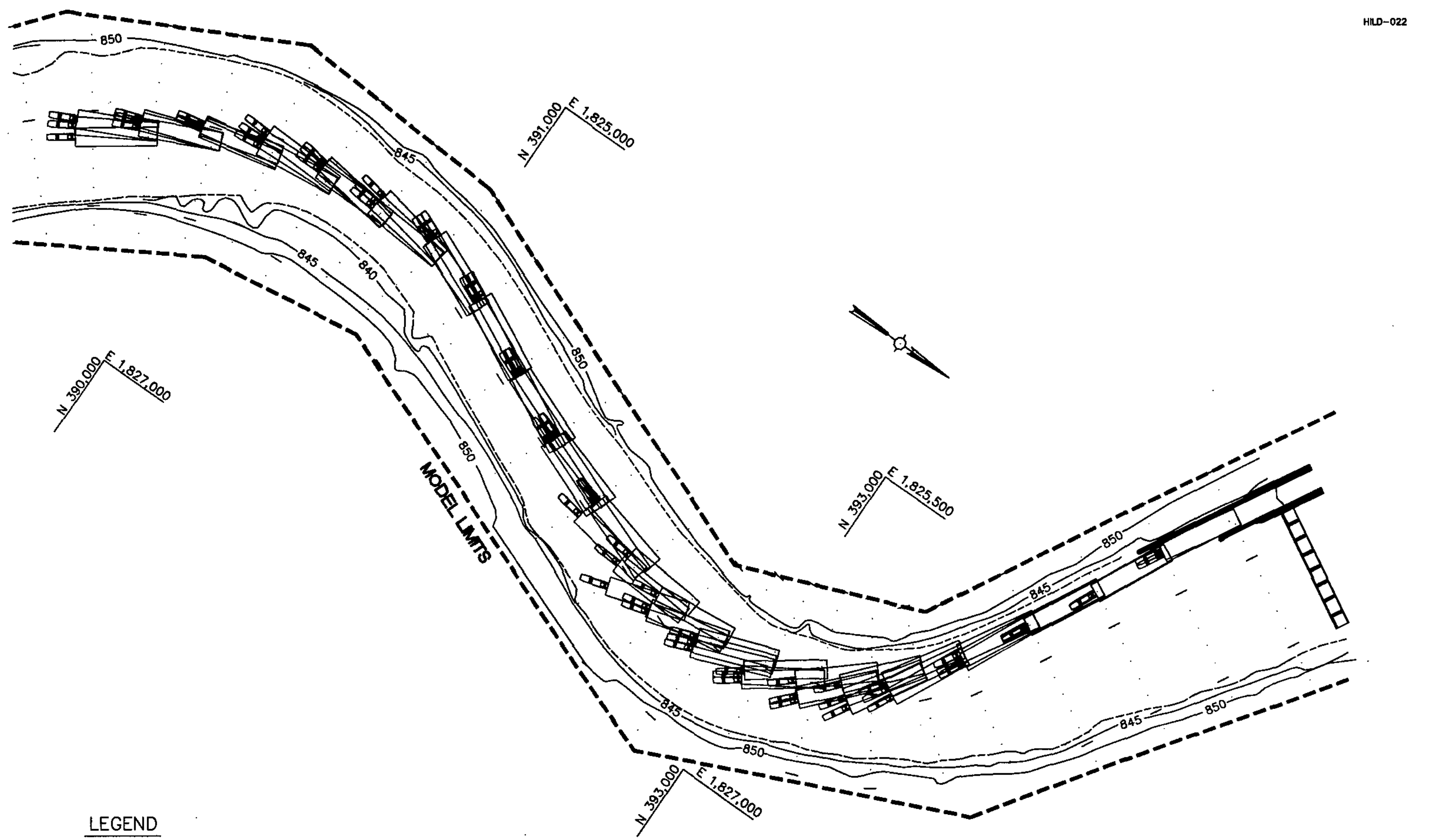
MODEL 0 5 10

VELOCITIES AND CURRENT DIRECTIONS

BASE TEST

DISCHARGE: 120,000 CFS
UPPER POOL: 832.0 FT

Plate 14



LEGEND

6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT

NOTE: ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO NGVD

SCALES

PROTOTYPE 0 500 1000

MODEL 0 5 10

TOW PATHS

BASE TEST

DISCHARGE: 5,000 CFS

UPPER POOL EL: 835.0 FT

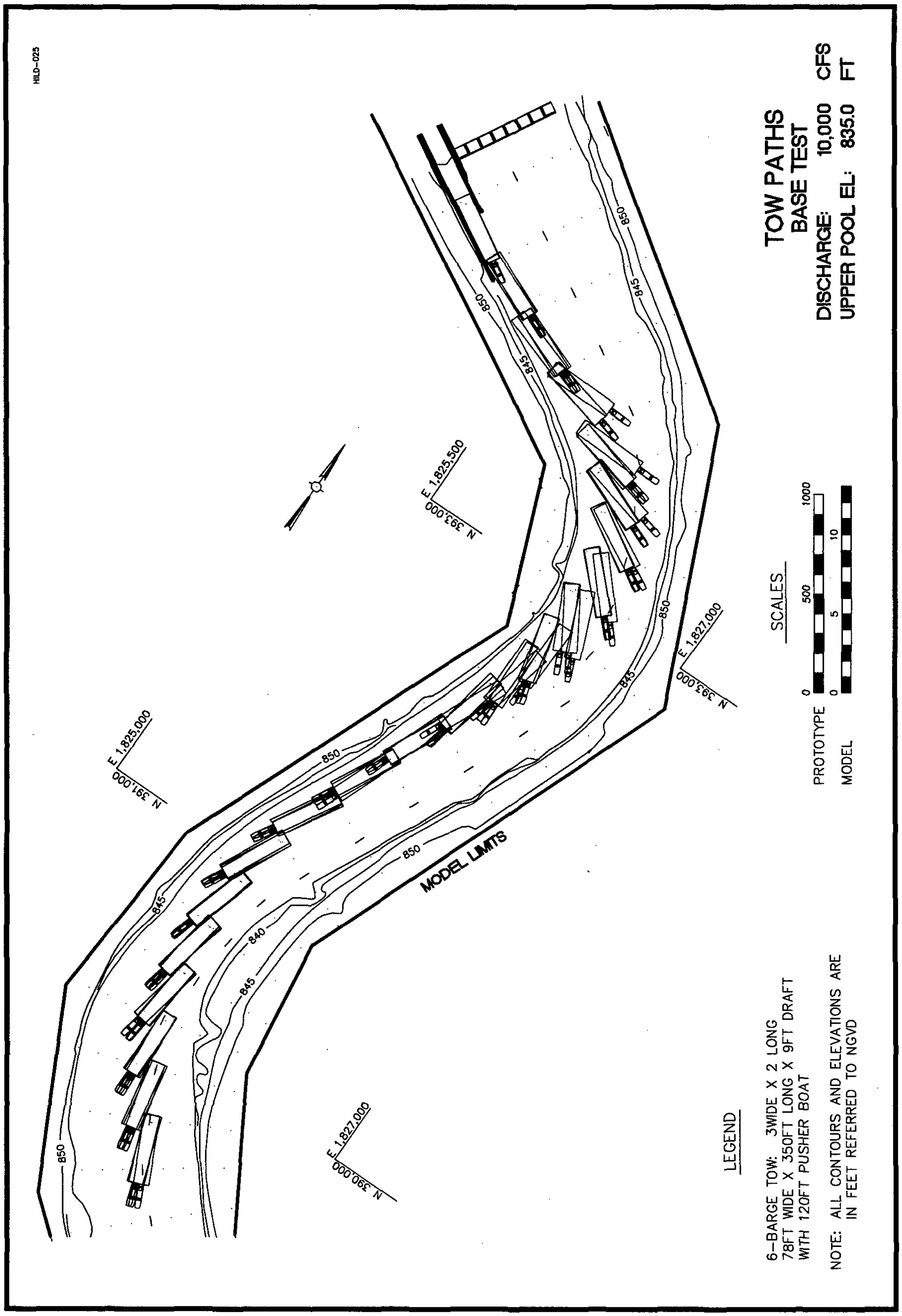
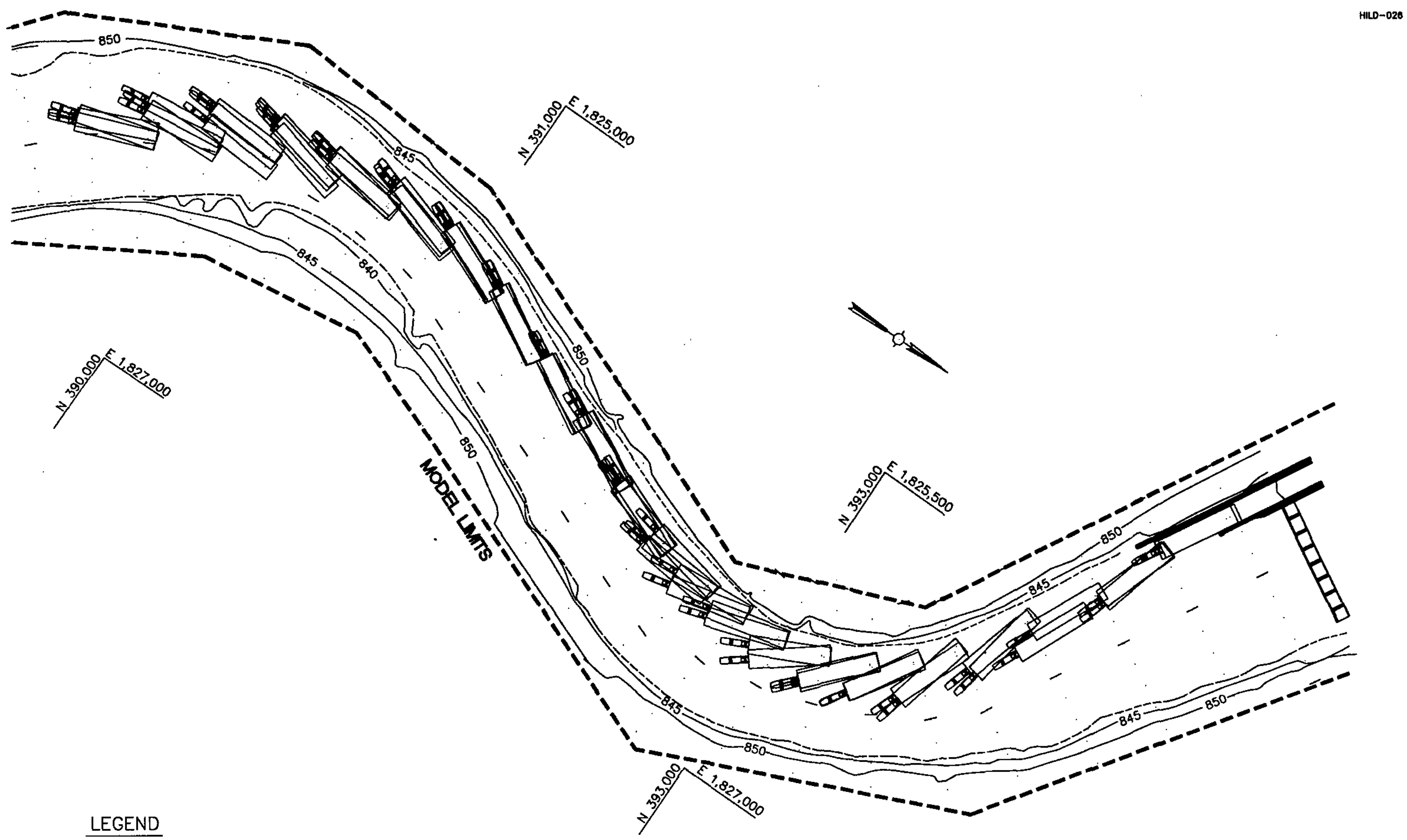

HILD-025
TOW PATHS
BASE TEST
DISCHARGE: 10,000 CFS
UPPER POOL EL: 835.0 FT
SCALES
PROTOTYPE 0 500 1000
MODEL 0 5 10
LEGEND
6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT
NOTE: ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO NGVD
MODEL LIMITS
E 1,825,500
N 393,000
E 1,825,000
N 391,000
E 1,827,000
N 393,000
E 1,827,000
N 390,000
850
845
840

Plate 16



LEGEND

6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT

NOTE: ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES

PROTOTYPE 0 500 1000

MODEL 0 5 10

TOW PATHS
BASE TEST

DISCHARGE: 13,600 CFS
UPPER POOL EL: 835.0 FT

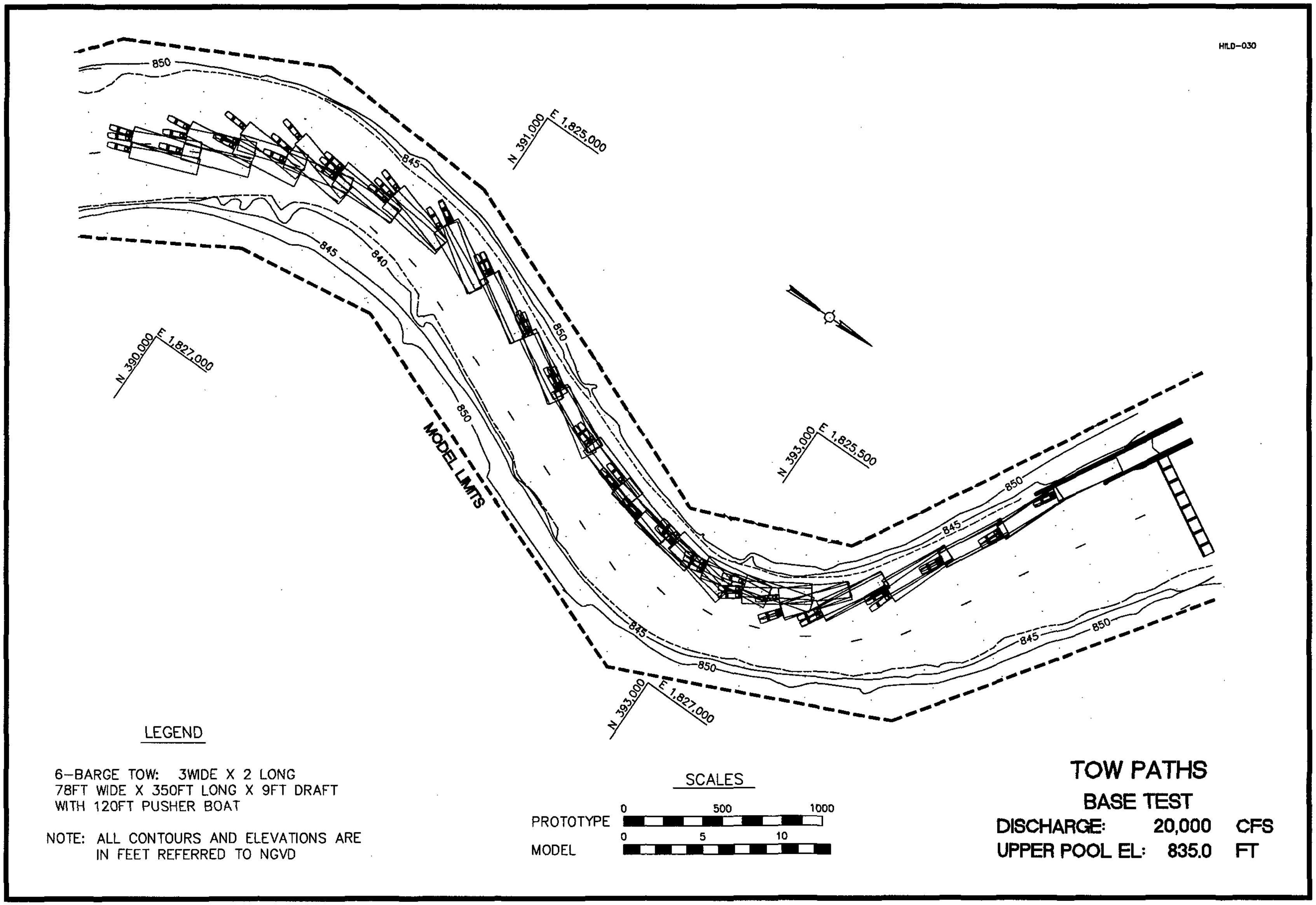
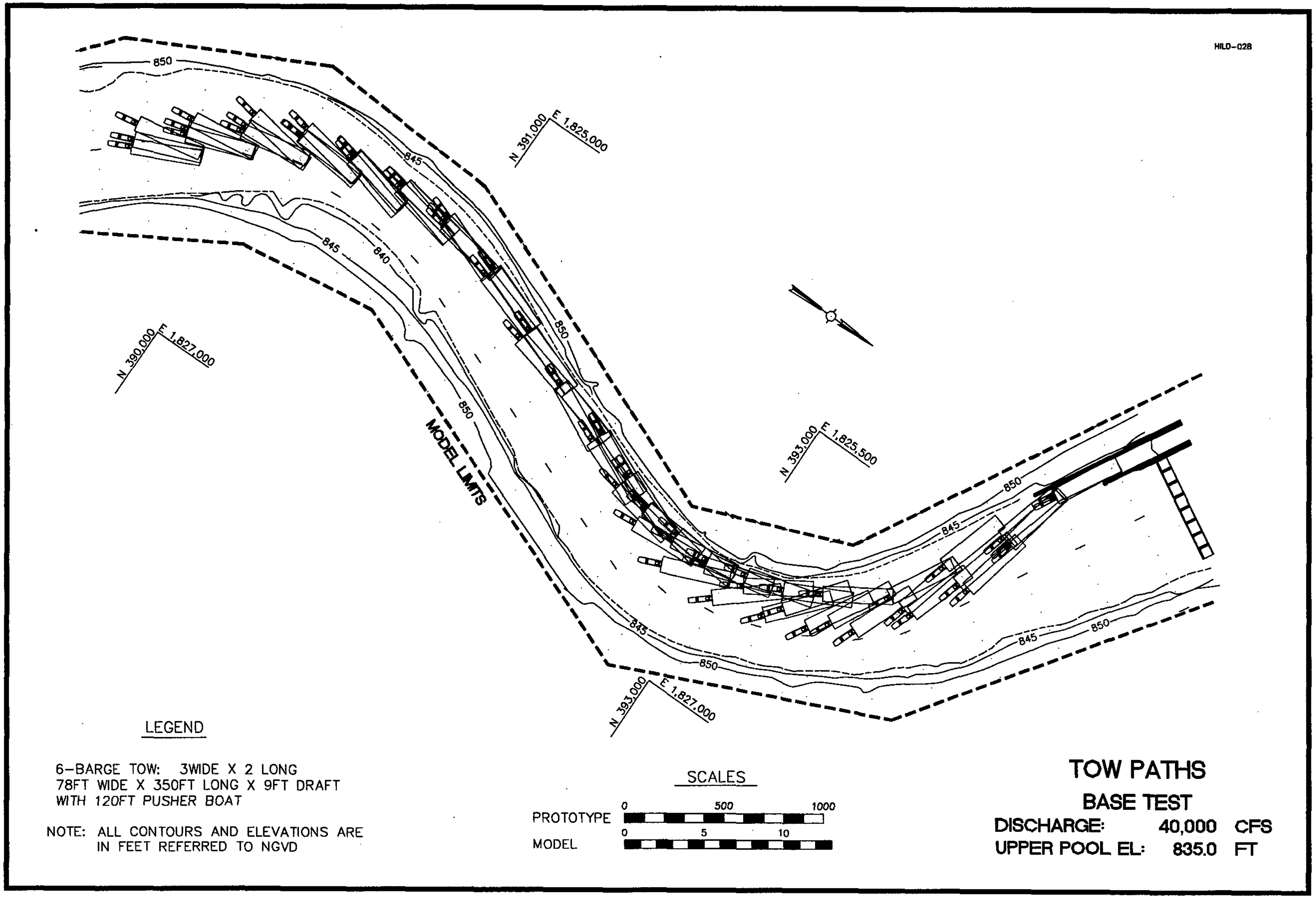

HILD-030
850
845
840
N 391,000 E 1,825,000
N 390,000 E 1,827,000
N 393,000 E 1,825,500
N 393,000 E 1,827,000
MODEL LIMITS
LEGEND
6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT
NOTE: ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO NGVD
SCALES
PROTOTYPE 0 500 1000
MODEL 0 5 10
TOW PATHS
BASE TEST
DISCHARGE: 20,000 CFS
UPPER POOL EL: 835.0 FT

Plate 18


HILD-028
850
845
840
850
845
850
845
850
850
845
850
N 391,000 E 1,825,000
N 390,000 E 1,827,000
N 393,000 E 1,825,500
N 393,000 E 1,827,000
MODEL LIMITS
LEGEND
6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT
NOTE: ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO NGVD
SCALES
PROTOTYPE 0 500 1000
MODEL 0 5 10
TOW PATHS
BASE TEST
DISCHARGE: 40,000 CFS
UPPER POOL EL: 835.0 FT

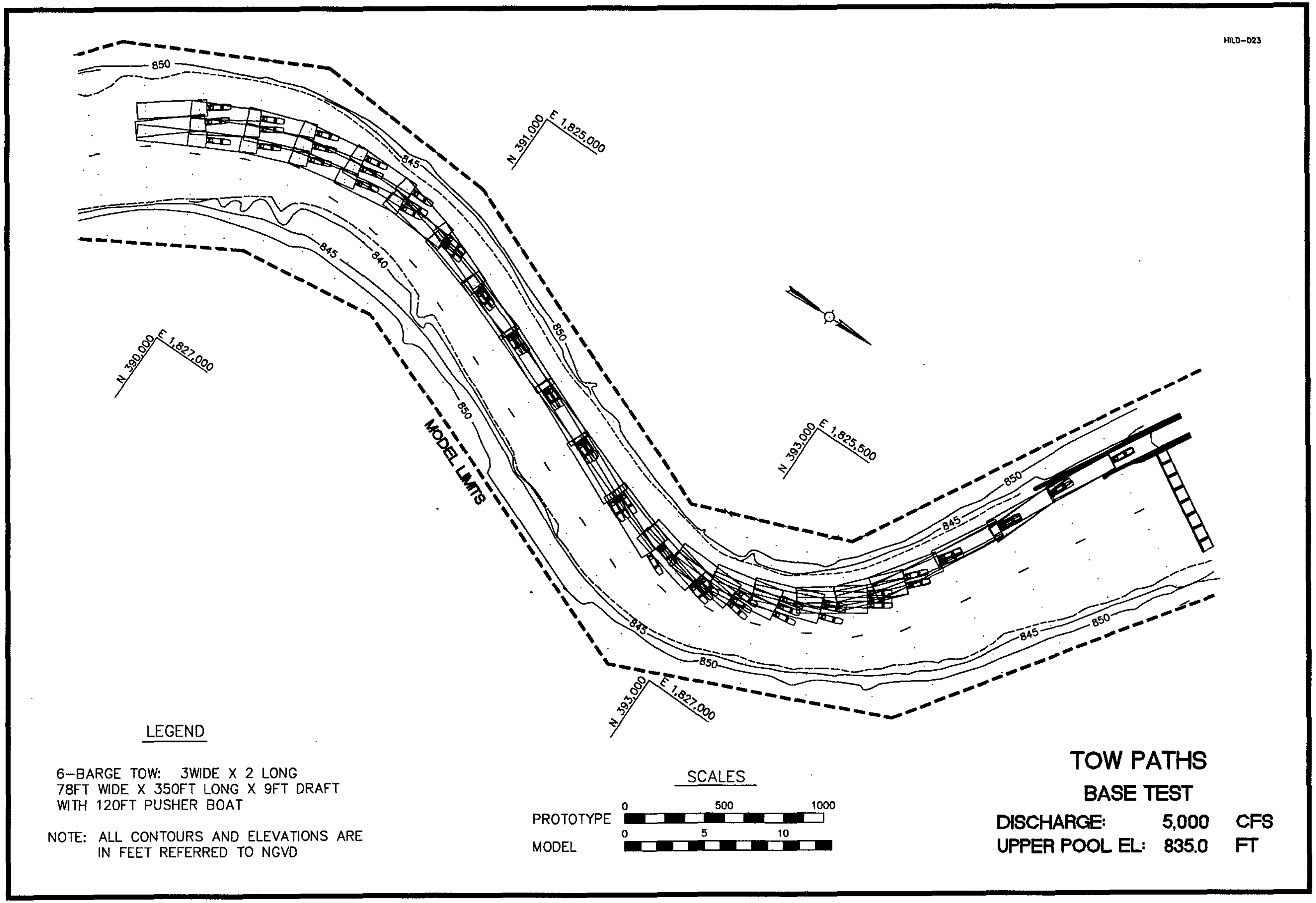
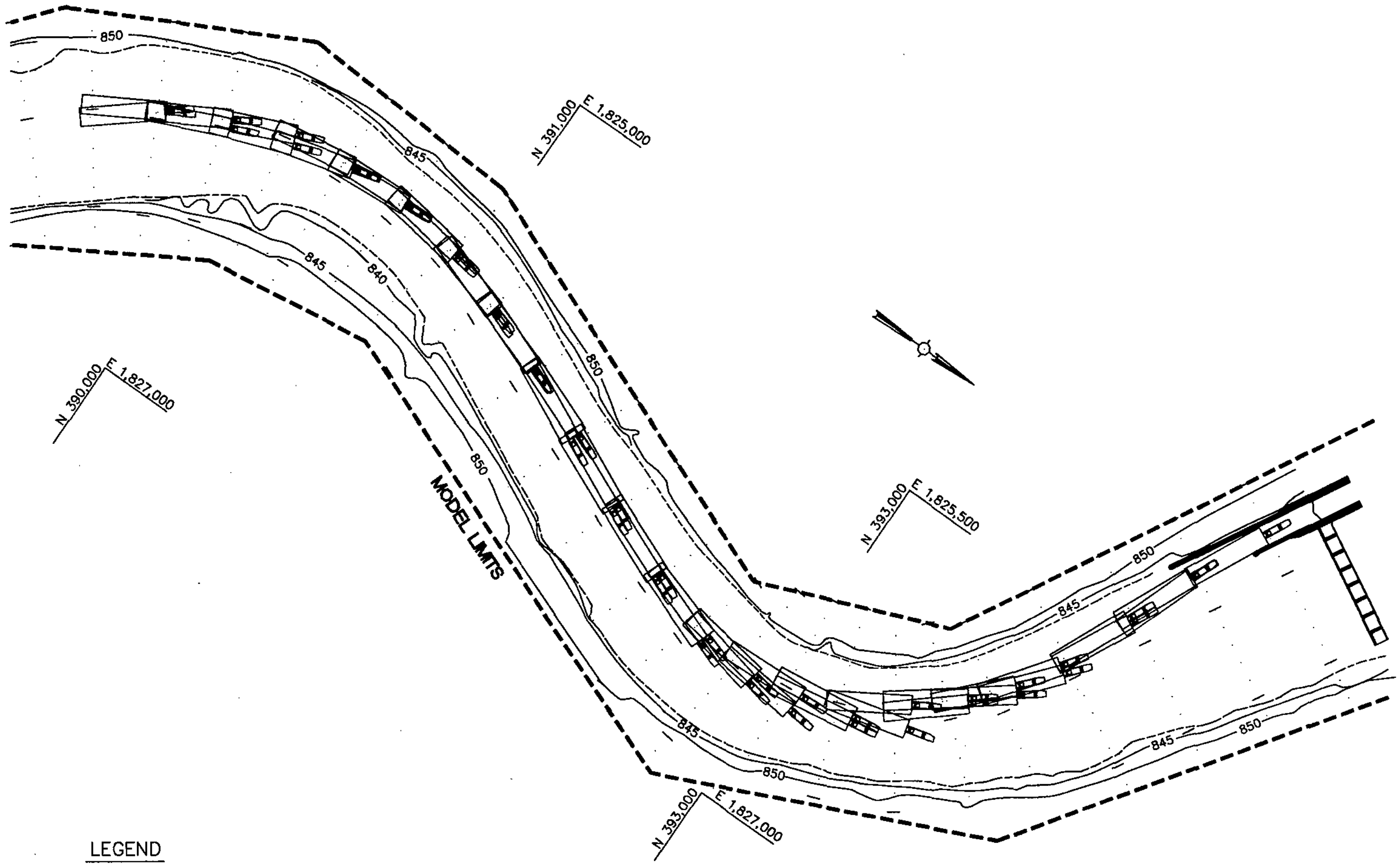

HILD-023
850
845
840
N 391,000
E 1,825,000
N 390,000
E 1,827,000
N 393,000
E 1,825,500
N 393,000
E 1,827,000
MODEL LIMITS
LEGEND
6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT
NOTE: ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO NGVD
SCALES
PROTOTYPE 0 500 1000
MODEL 0 5 10
TOW PATHS
BASE TEST
DISCHARGE: 5,000 CFS
UPPER POOL EL: 835.0 FT

Plate 20



LEGEND

6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT

NOTE: ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO NGVD

SCALES

PROTOTYPE 0 500 1000

MODEL 0 5 10

TOW PATHS

BASE TEST

DISCHARGE: 10,000 CFS
UPPER POOL EL: 835.0 FT

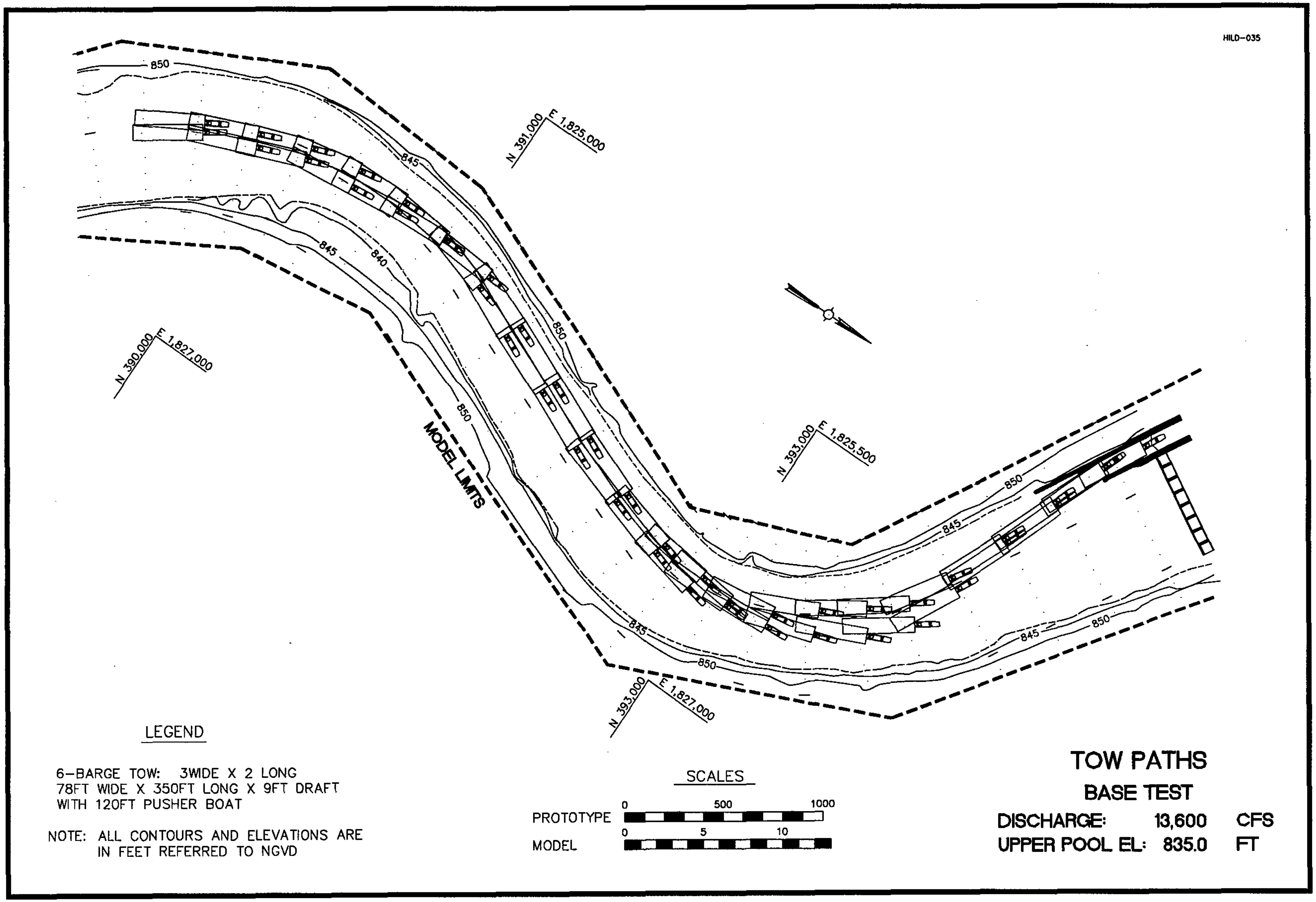

HILD-035
850
845
840
N 391,000
E 1,825,000
N 390,000
E 1,827,000
N 393,000
E 1,825,500
N 393,000
E 1,827,000
MODEL LIMITS
LEGEND
6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT
NOTE: ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO NGVD
SCALES
PROTOTYPE 0 500 1000
MODEL 0 5 10
TOW PATHS
BASE TEST
DISCHARGE: 13,600 CFS
UPPER POOL EL: 835.0 FT

Plate 22

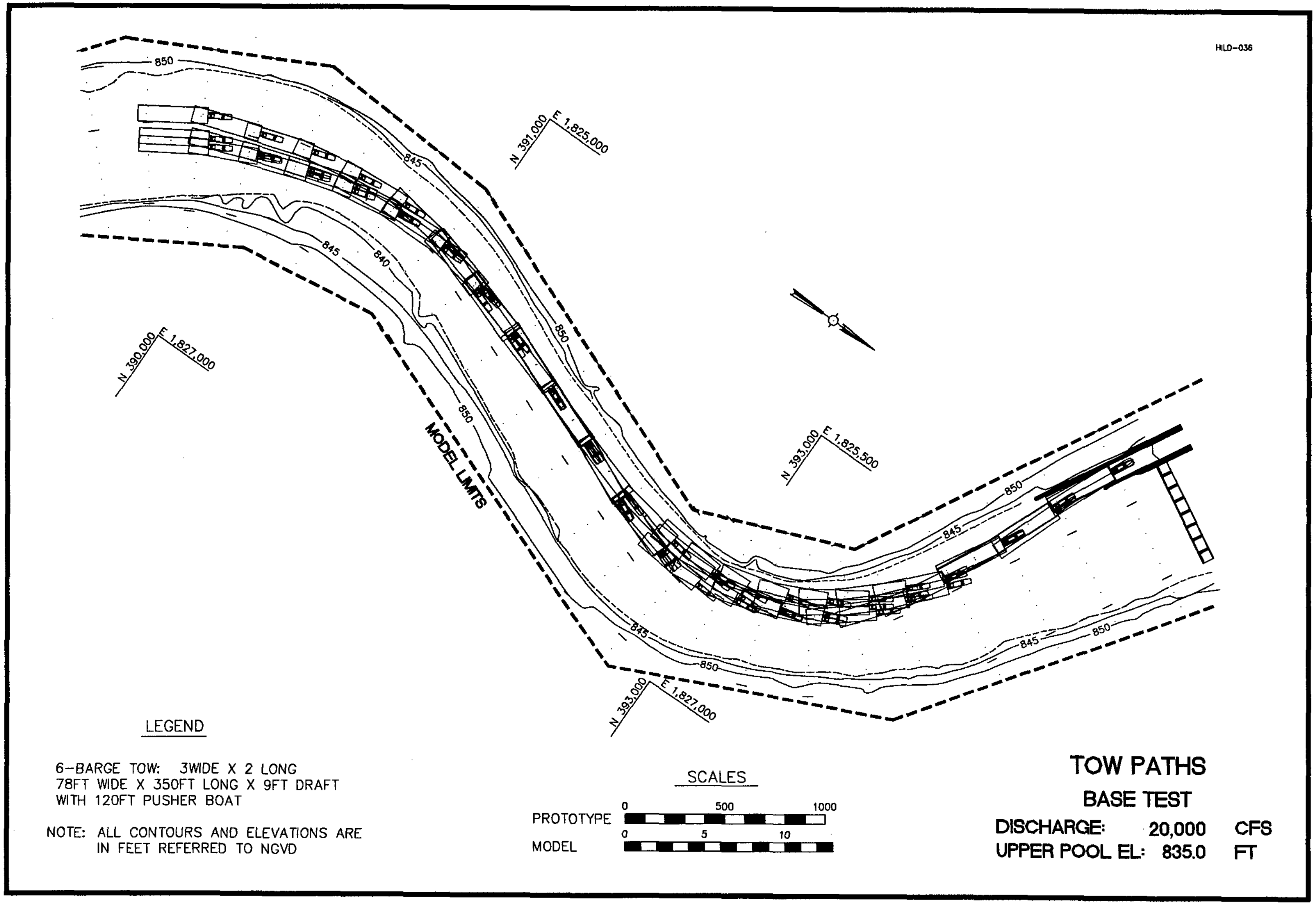

HILD-036
850
845
840
850
N 391,000
E 1,825,000
N 390,000
E 1,827,000
N 393,000
E 1,825,500
N 393,000
E 1,827,000
MODEL LIMITS
LEGEND
6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT
NOTE: ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO NGVD
SCALES
PROTOTYPE 0 500 1000
MODEL 0 5 10
TOW PATHS
BASE TEST
DISCHARGE: 20,000 CFS
UPPER POOL EL: 835.0 FT

Plate 23

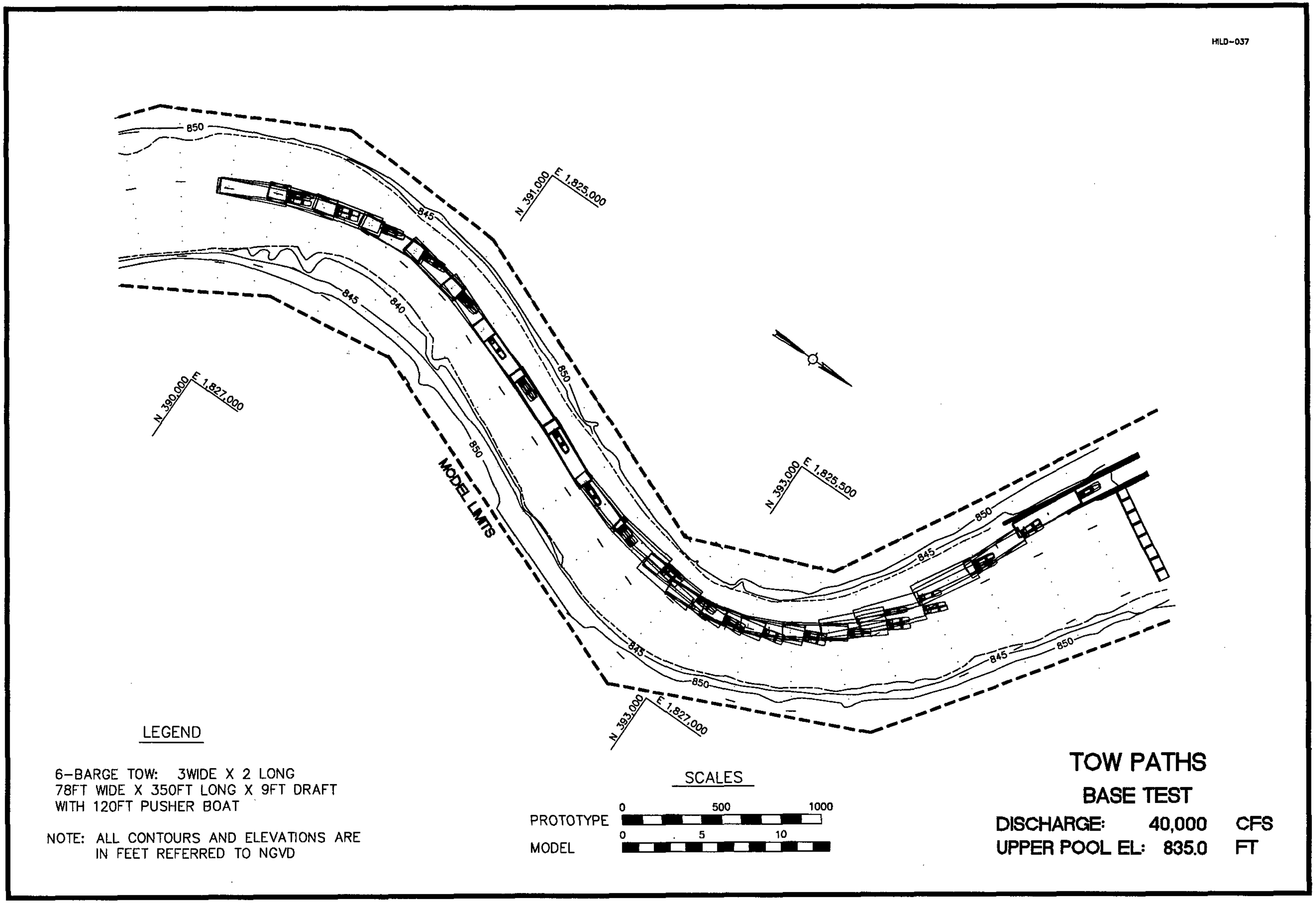
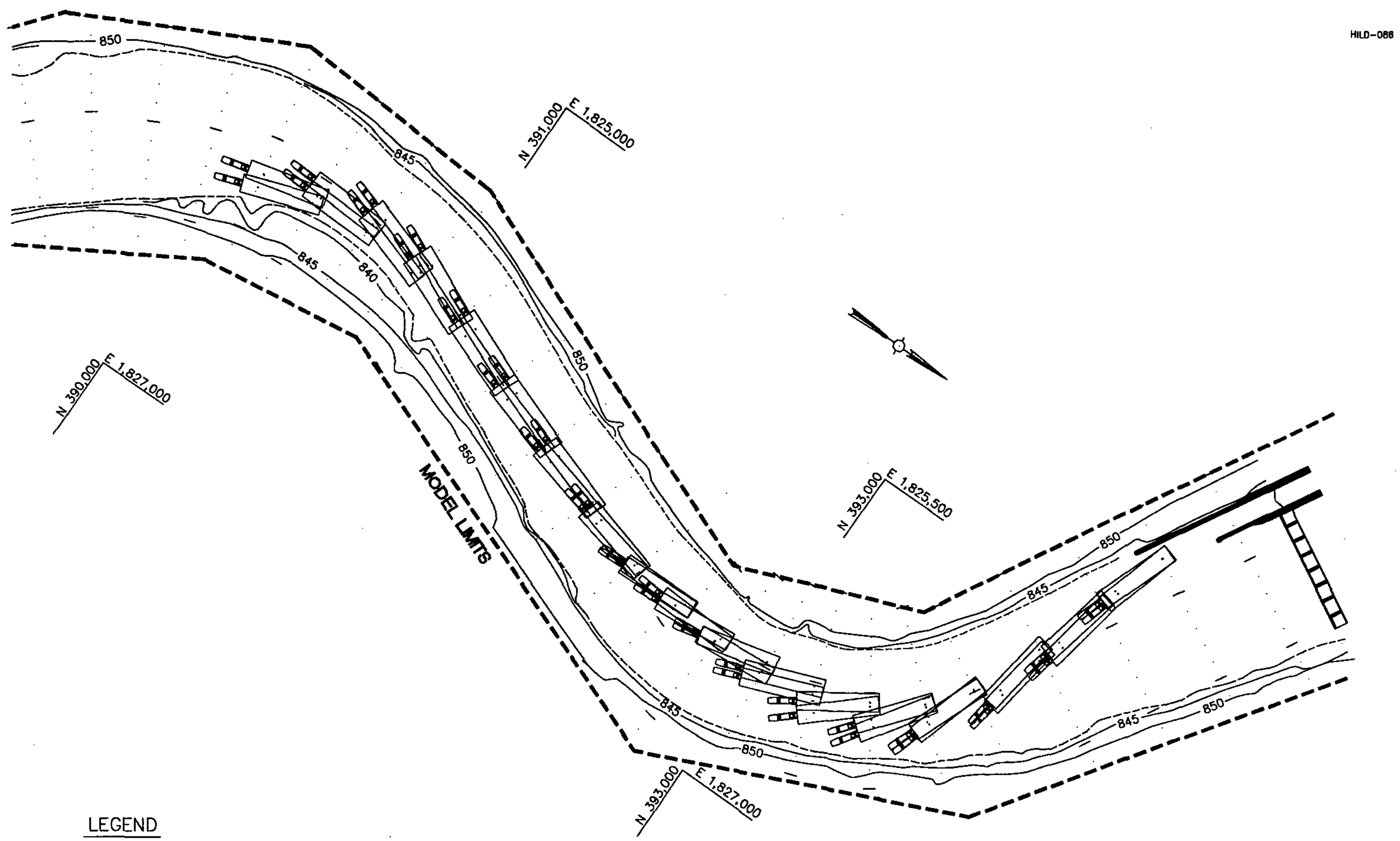

HLD-037
850
845
840
MODEL LIMITS
N 391,000
E 1,825,000
N 390,000
E 1,827,000
N 393,000
E 1,825,500
N 393,000
E 1,827,000
LEGEND
6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT
NOTE: ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO NGVD
SCALES
PROTOTYPE 0 500 1000
MODEL 0 5 10
TOW PATHS
BASE TEST
DISCHARGE: 40,000 CFS
UPPER POOL EL: 835.0 FT

Plate 24



LEGEND

6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT

NOTE: ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES

PROTOTYPE 0 500 1000

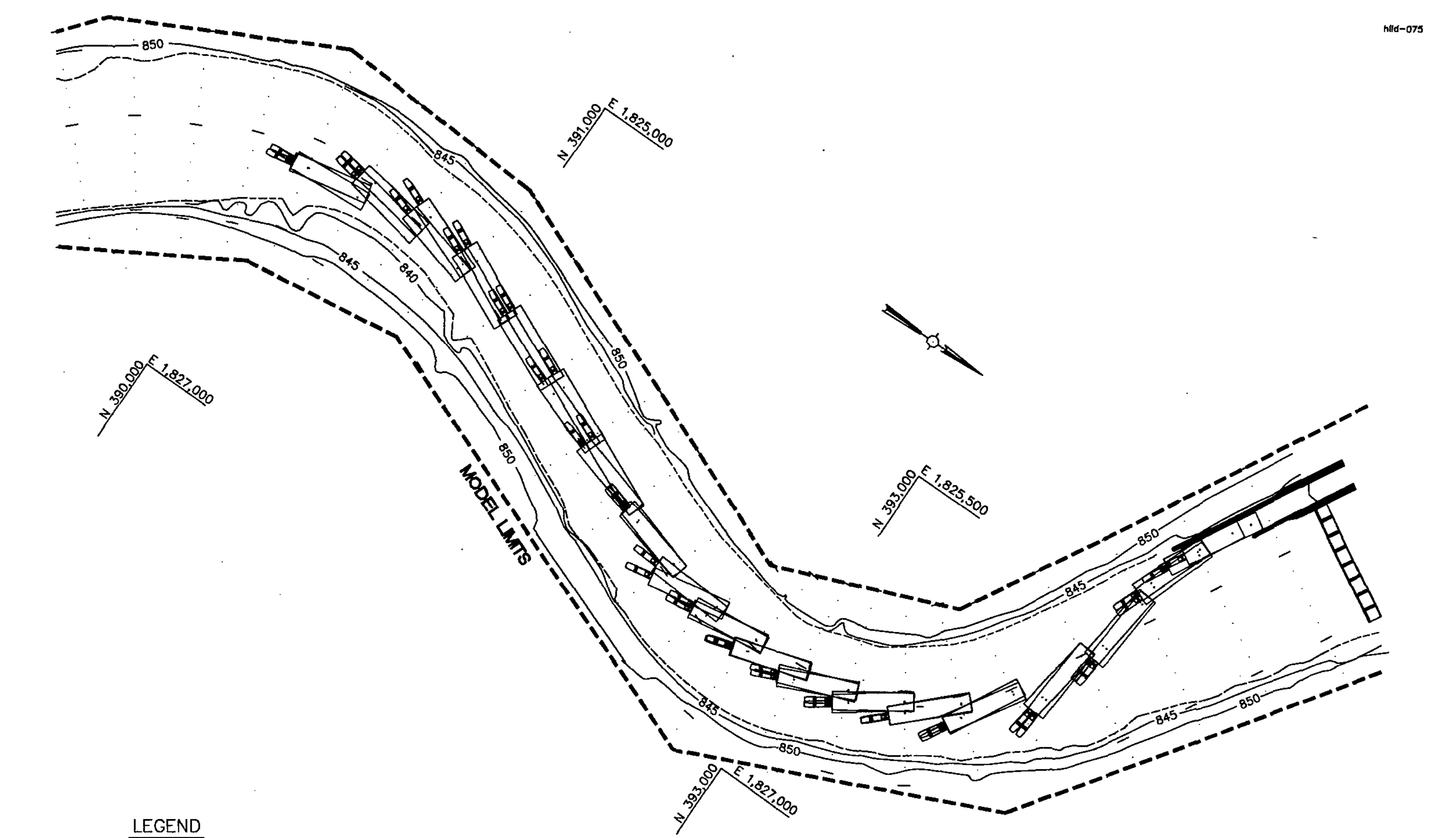
MODEL 0 5 10

TOW PATHS

BASE TEST

DISCHARGE: 5,000 CFS

UPPER POOL EL: 835.0 FT



LEGEND

6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT

NOTE: ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO NGVD

SCALES

PROTOTYPE 0 500 1000

MODEL 0 5 10

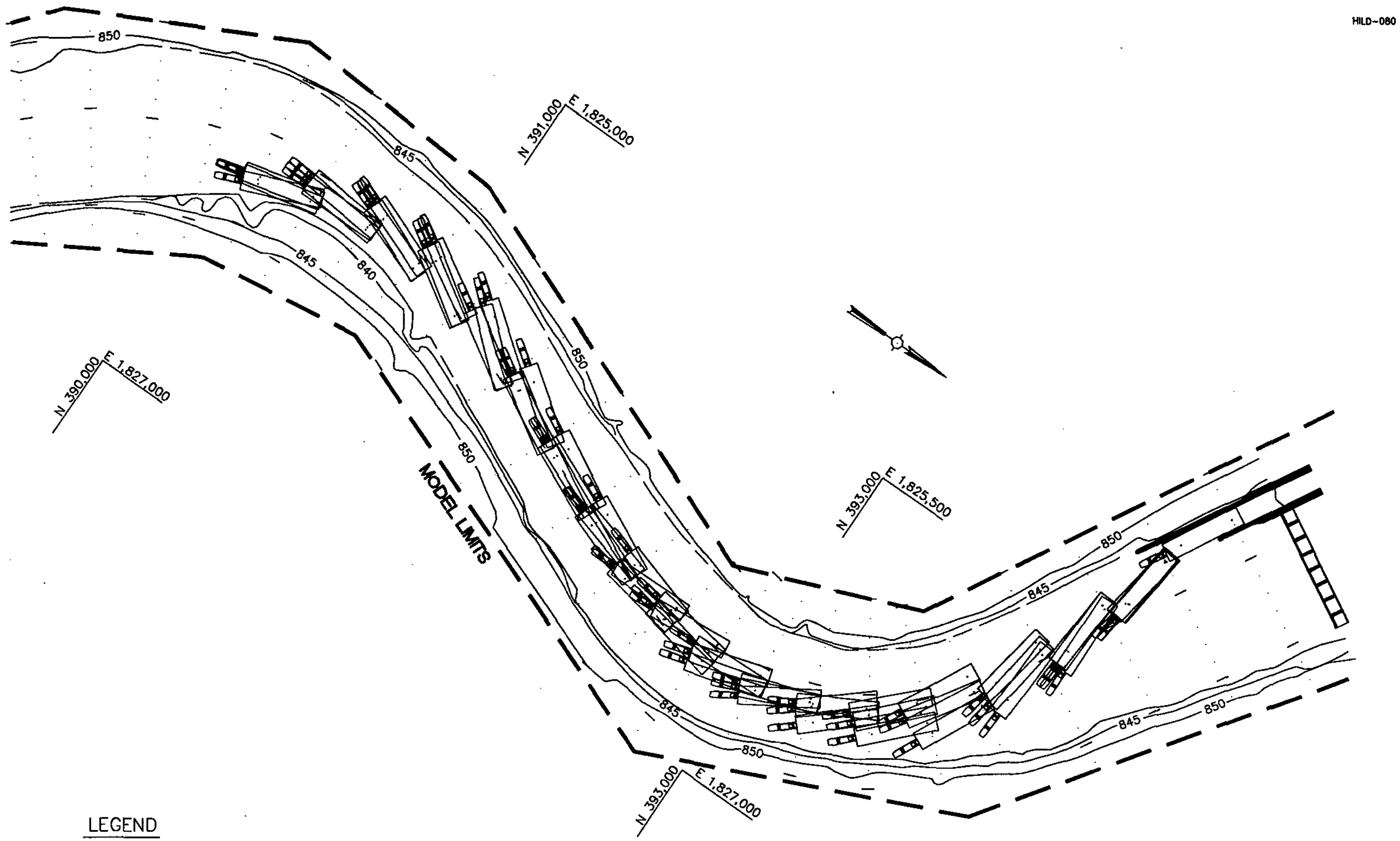
TOW PATHS

BASE TEST

DISCHARGE: 10,000 CFS

UPPER POOL EL: 835.0 FT

Plate 26



LEGEND

6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT

NOTE: ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO NGVD

SCALES

PROTOTYPE 0 500 1000

MODEL 0 5 10

TOW PATHS

BASE TEST

DISCHARGE: 20,000 CFS

UPPER POOL EL: 835.0 FT

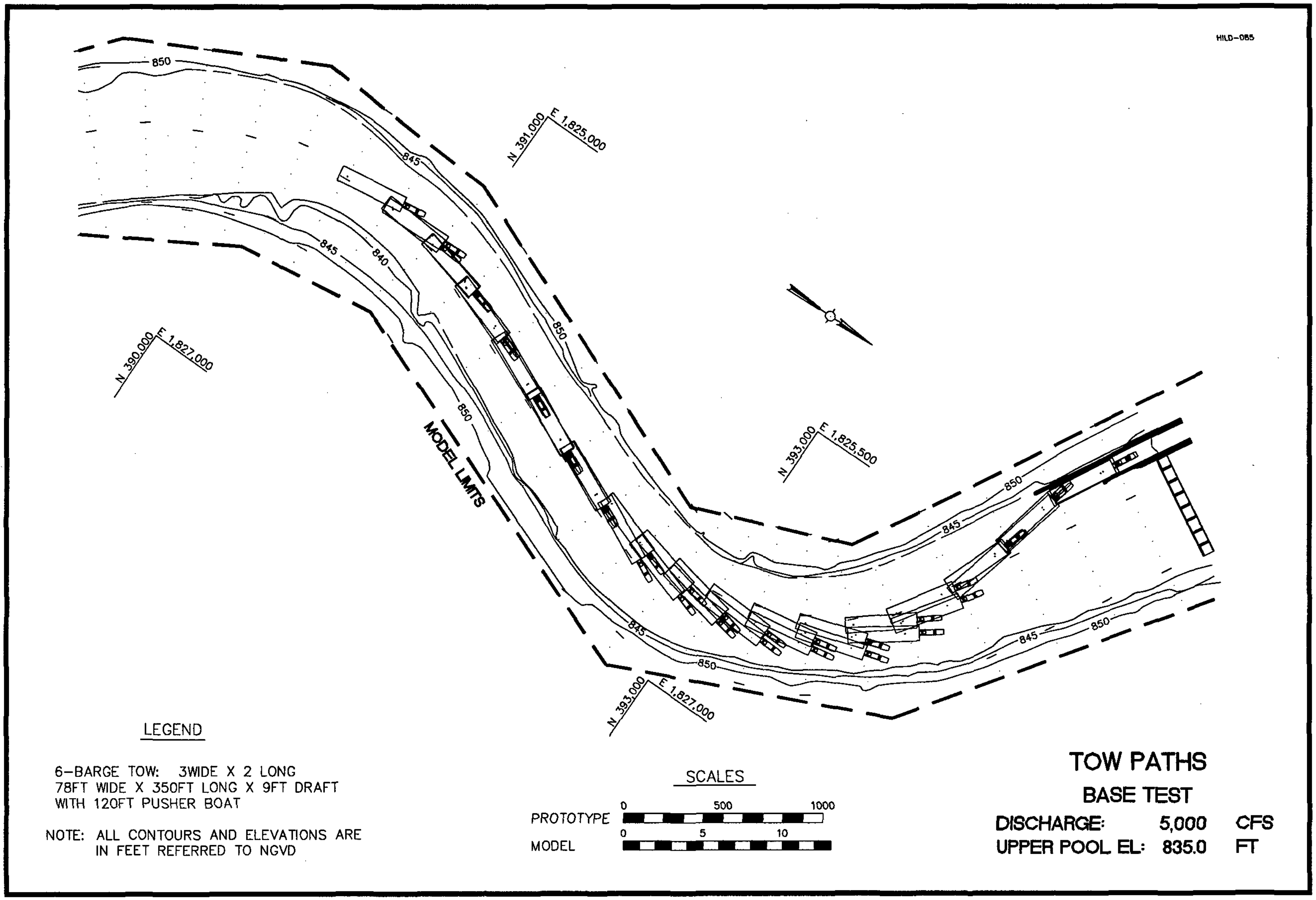

HILD-085
850
845
840
MODEL LIMITS
N 391,000
E 1,825,000
N 390,000
E 1,827,000
N 393,000
E 1,825,500
N 393,000
E 1,827,000
LEGEND
6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT
NOTE: ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO NGVD
SCALES
PROTOTYPE 0 500 1000
MODEL 0 5 10
TOW PATHS
BASE TEST
DISCHARGE: 5,000 CFS
UPPER POOL EL: 835.0 FT

Plate 28

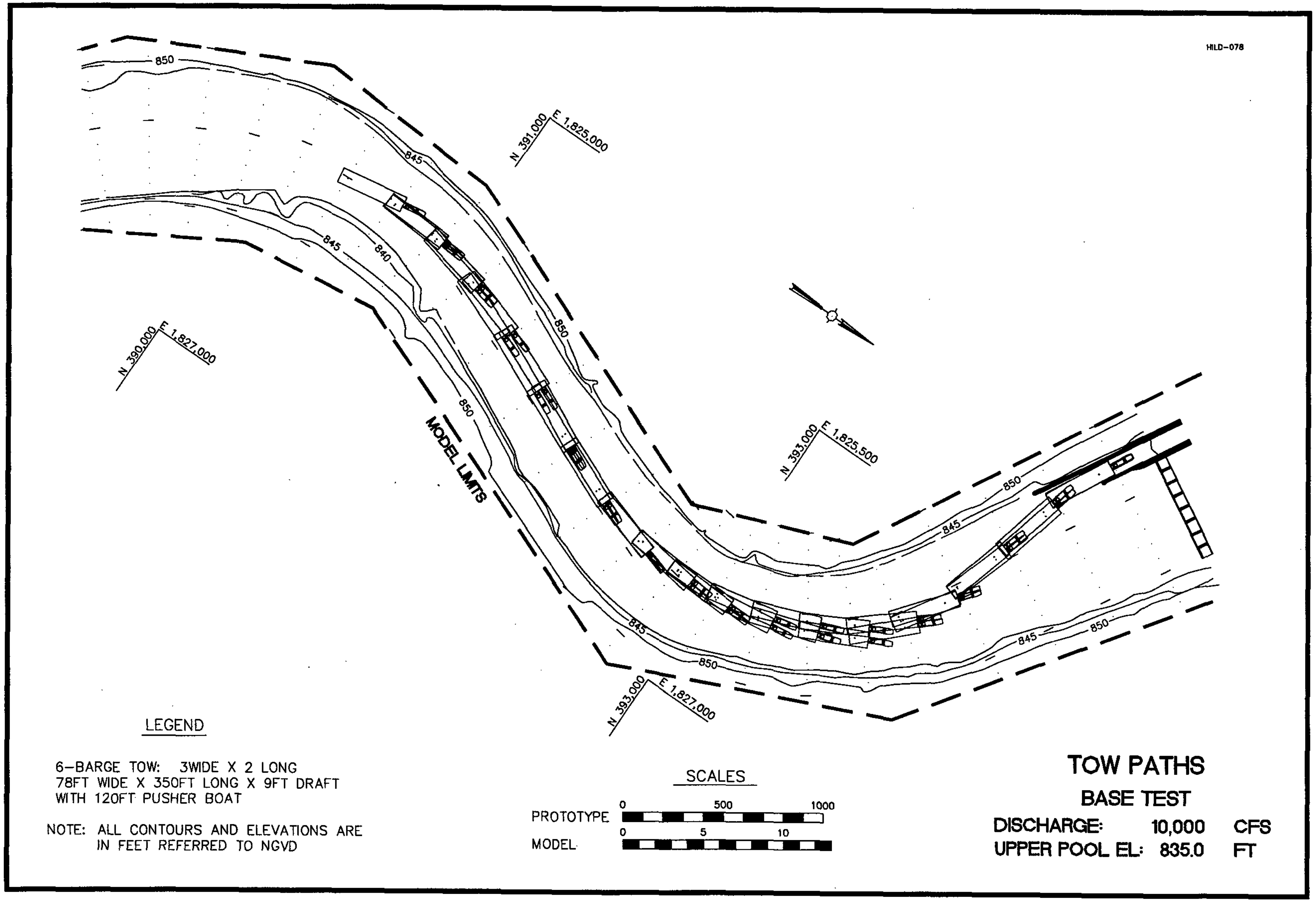
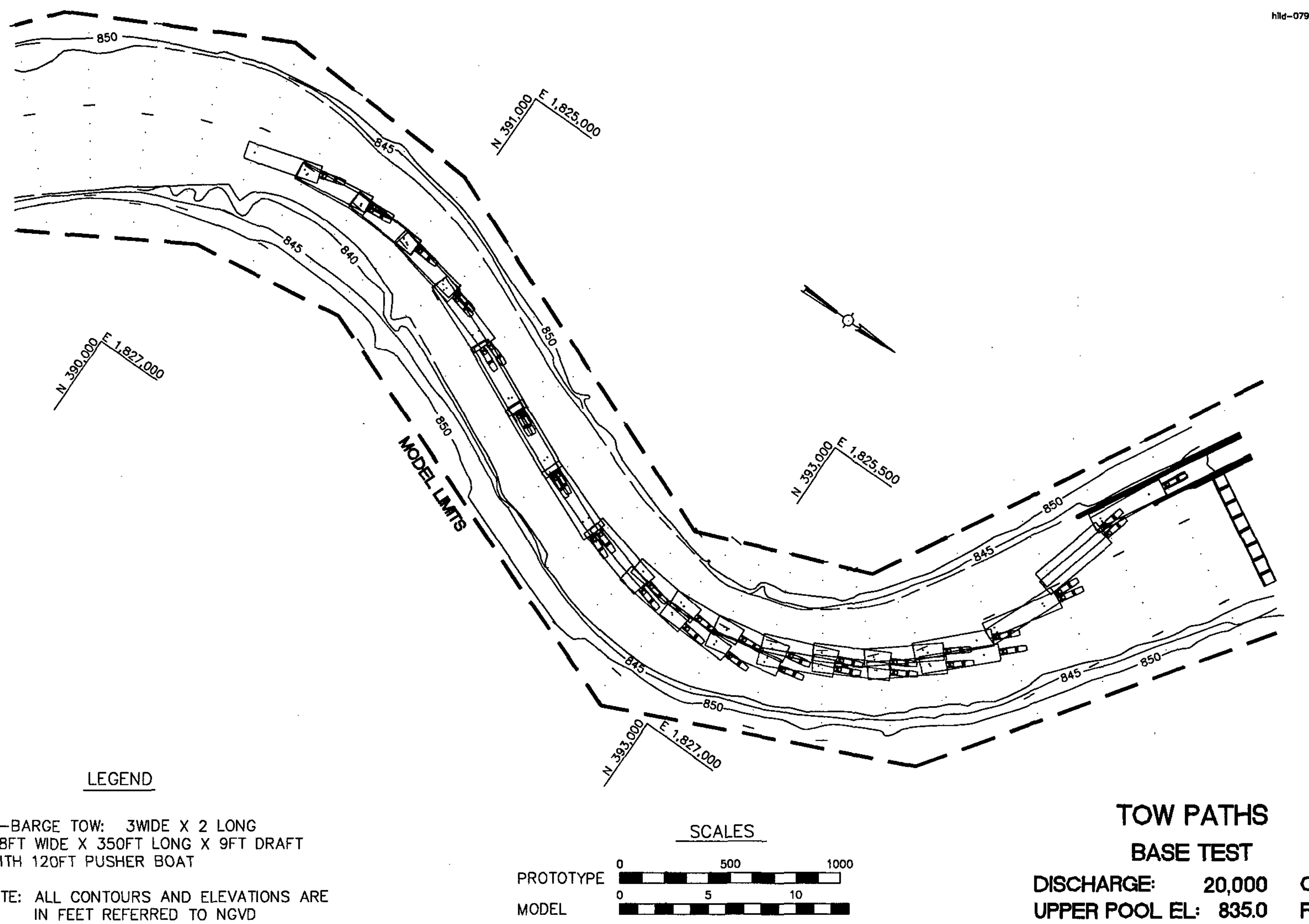

HILD-078
850
845
840
MODEL LIMITS
N 391,000
E 1,825,000
N 390,000
E 1,827,000
N 393,000
E 1,825,500
N 393,000
E 1,827,000
LEGEND
6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT
NOTE: ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO NGVD
SCALES
PROTOTYPE 0 500 1000
MODEL 0 5 10
TOW PATHS
BASE TEST
DISCHARGE: 10,000 CFS
UPPER POOL EL: 835.0 FT

Plate 29



LEGEND

6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT

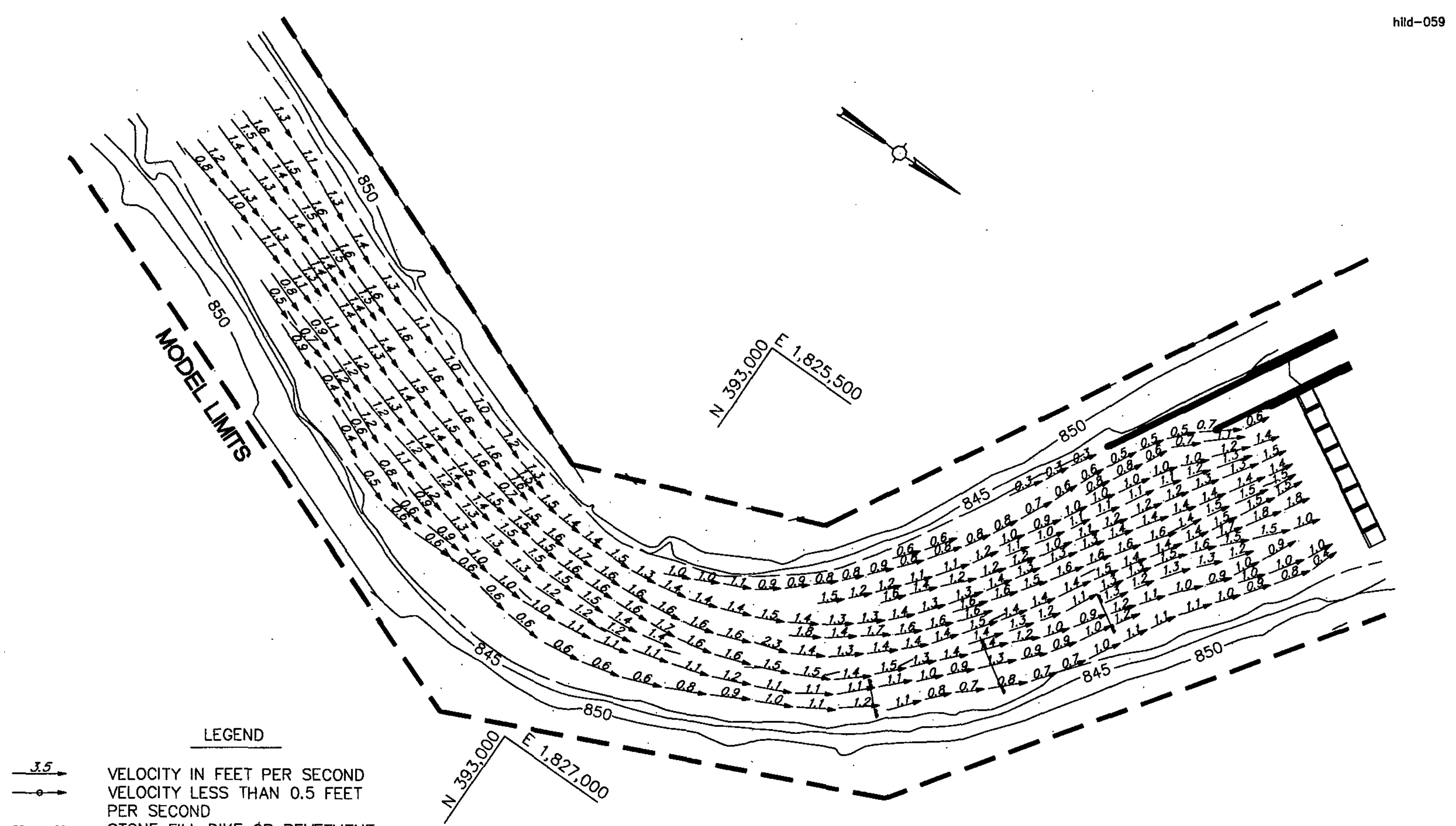
NOTE: ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO NGVD

TOW PATHS

BASE TEST

DISCHARGE: 20,000 CFS
UPPER POOL EL: 835.0 FT

Plate 30



LEGEND

3.5	VELOCITY IN FEET PER SECOND
	VELOCITY LESS THAN 0.5 FEET PER SECOND
	STONE FILL DIKE OR REVETMENT

NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES IN FEET

PROTOTYPE 0 500 1000

MODEL 0 5 10

VELOCITIES AND CURRENT DIRECTIONS

PLAN A

DISCHARGE: 10,000 CFS
UPPER POOL EL: 835.0 FT

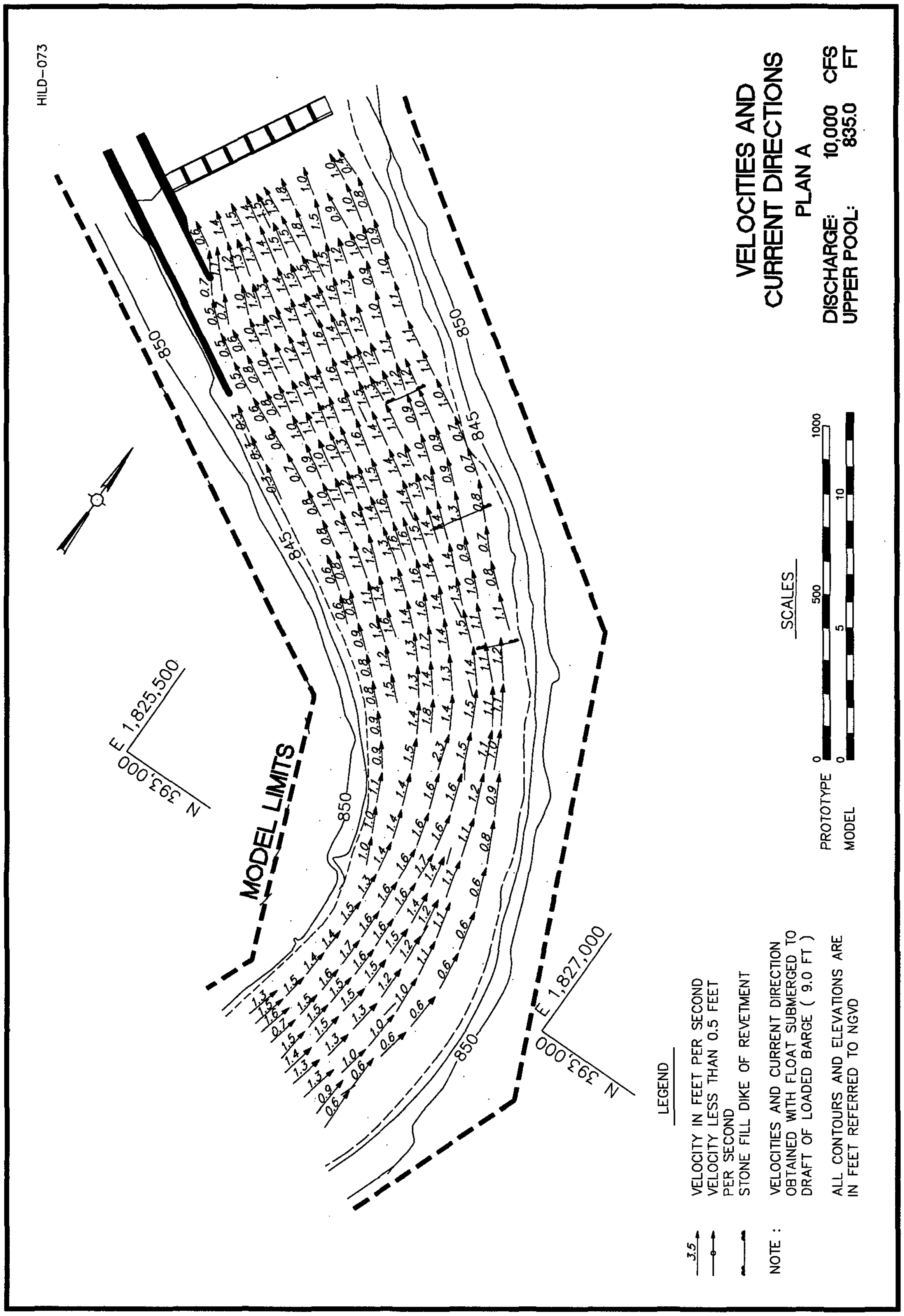
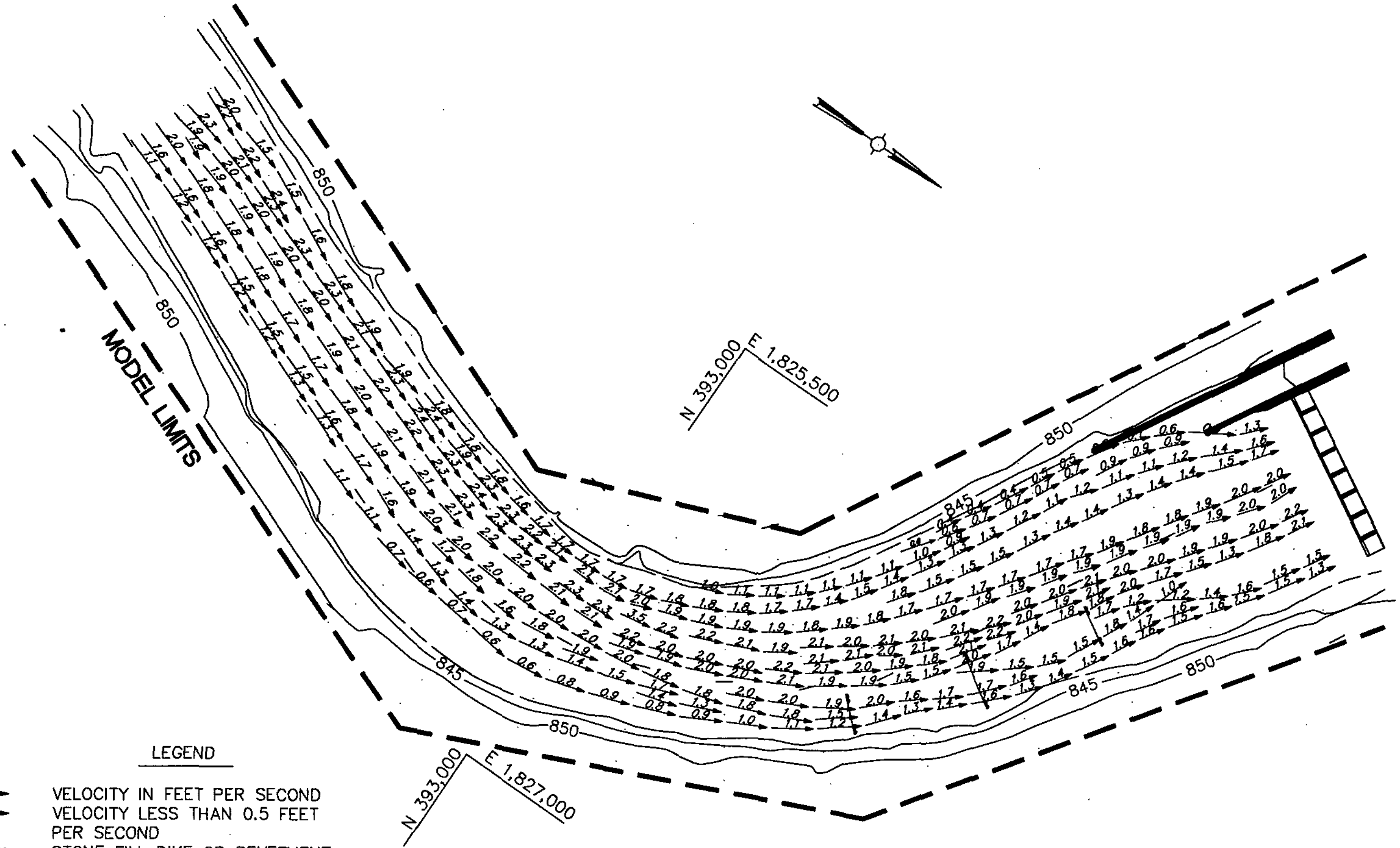

HILD-073
VELOCITIES AND
CURRENT DIRECTIONS
PLAN A
DISCHARGE: 10,000 CFS
UPPER POOL: 835.0 FT
MODEL LIMITS
E 1,825,500
N 393,000
E 1,827,000
N 393,000
850
845
SCALES
PROTOTYPE 0 500 1000
MODEL 0 5 10
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
STONE FILL DIKE OF REVETMENT
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

Plate 32

HILD-060



LEGEND

3.5 — VELOCITY IN FEET PER SECOND

VELOCITY LESS THAN 0.5 FEET PER SECOND

STONE FILL DIKE OR REVETMENT

NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES IN FEET

PROTOTYPE 0 500 1000

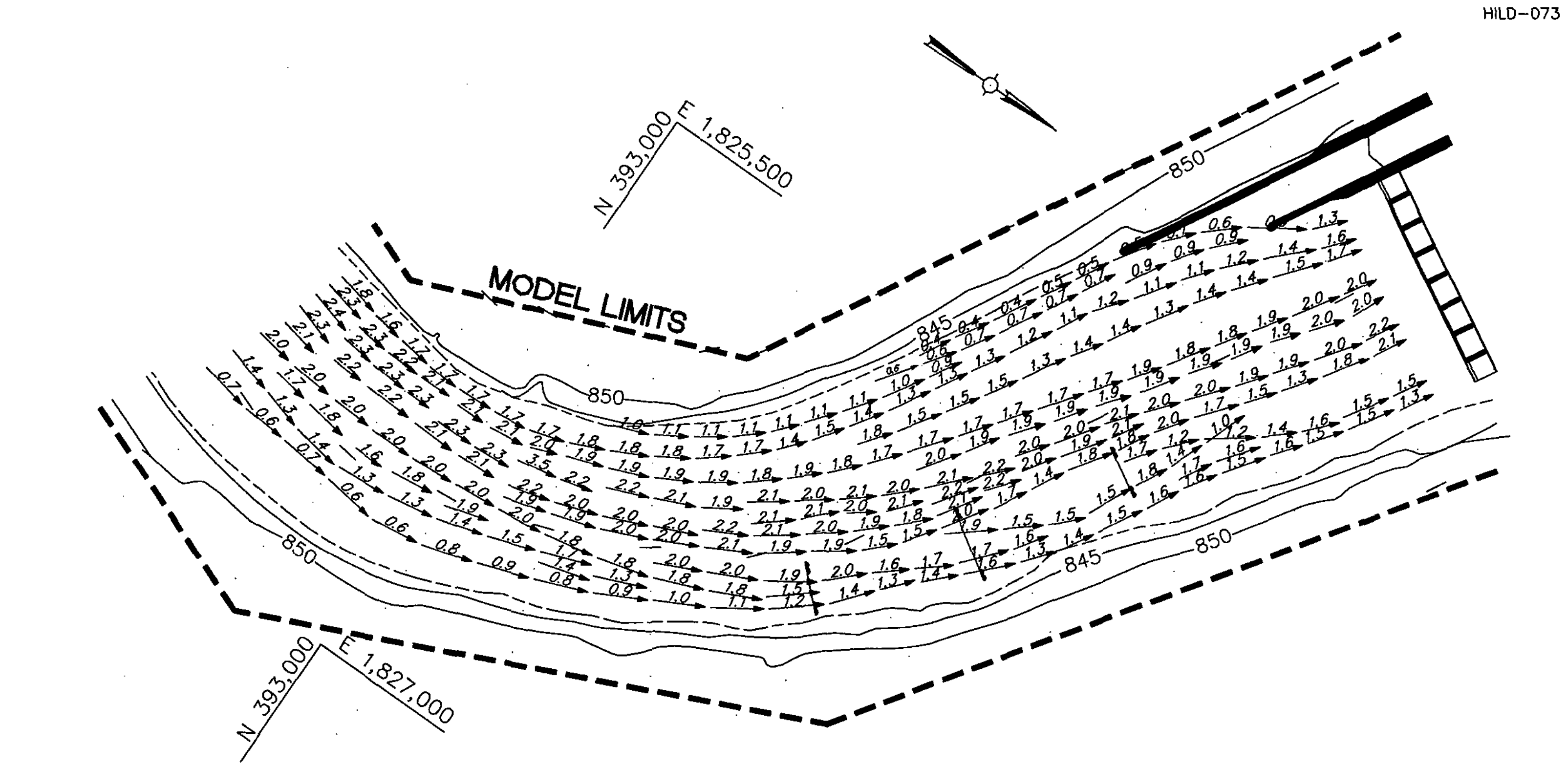
MODEL 0 5 10

VELOCITIES AND CURRENT DIRECTIONS

PLAN A

DISCHARGE: 13,600 CFS

UPPER POOL EL: 835.0 FT



LEGEND

3.5	VELOCITY IN FEET PER SECOND
	VELOCITY LESS THAN 0.5 FEET PER SECOND
	STONE FILL DIKE OR REVETMENT

NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES

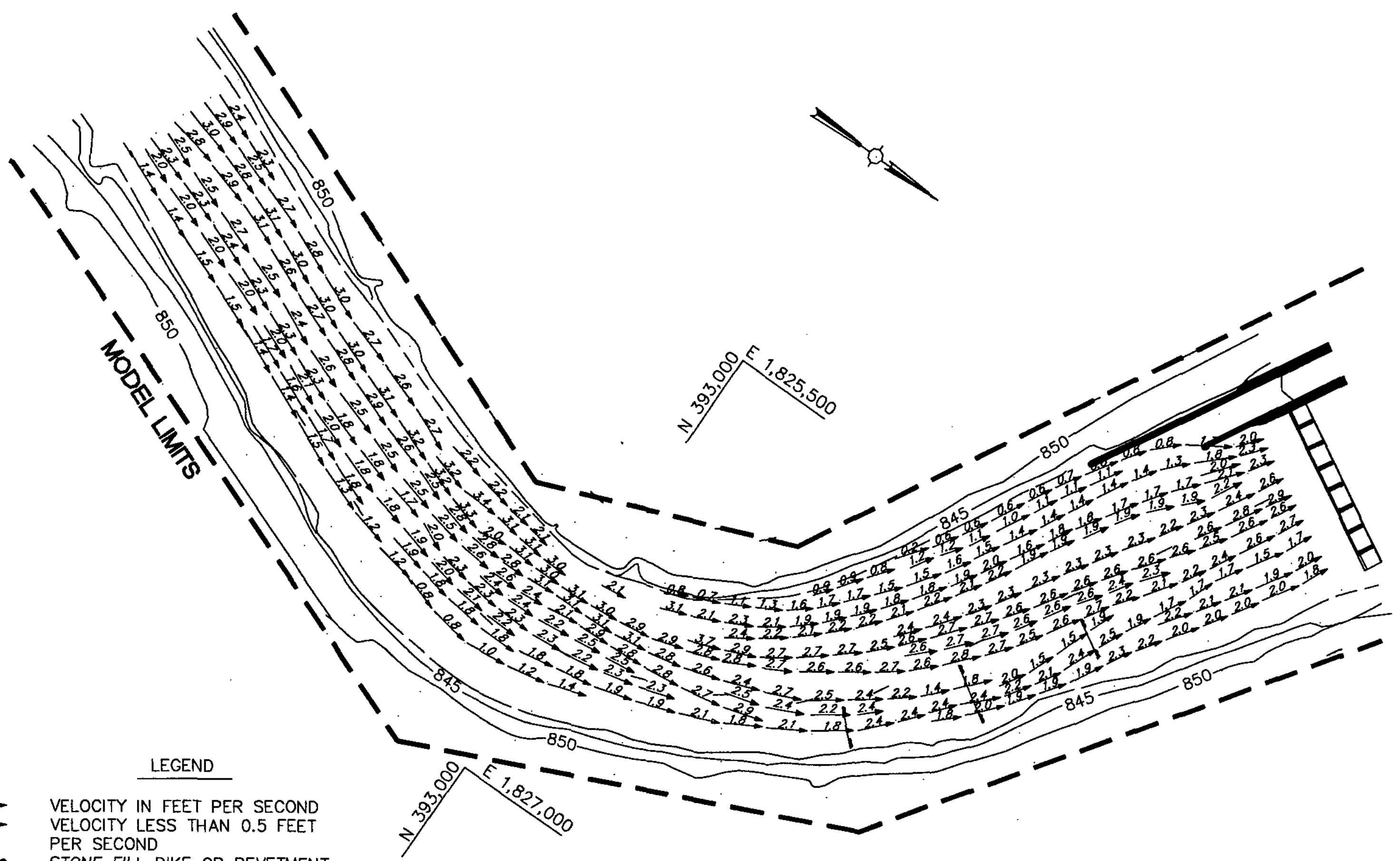
PROTOTYPE 0 500 1000

MODEL 0 5 10

VELOCITIES AND CURRENT DIRECTIONS
PLAN A

DISCHARGE: 13,600 CFS
UPPER POOL: 835.0 FT

HILD-061



LEGEND

3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
STONE FILL DIKE OR REVETMENT

NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES IN FEET

PROTOTYPE 0 500 1000
MODEL 0 5 10

VELOCITIES AND CURRENT DIRECTIONS

PLAN A

DISCHARGE: 20,000 CFS
UPPER POOL EL: 835.0 FT

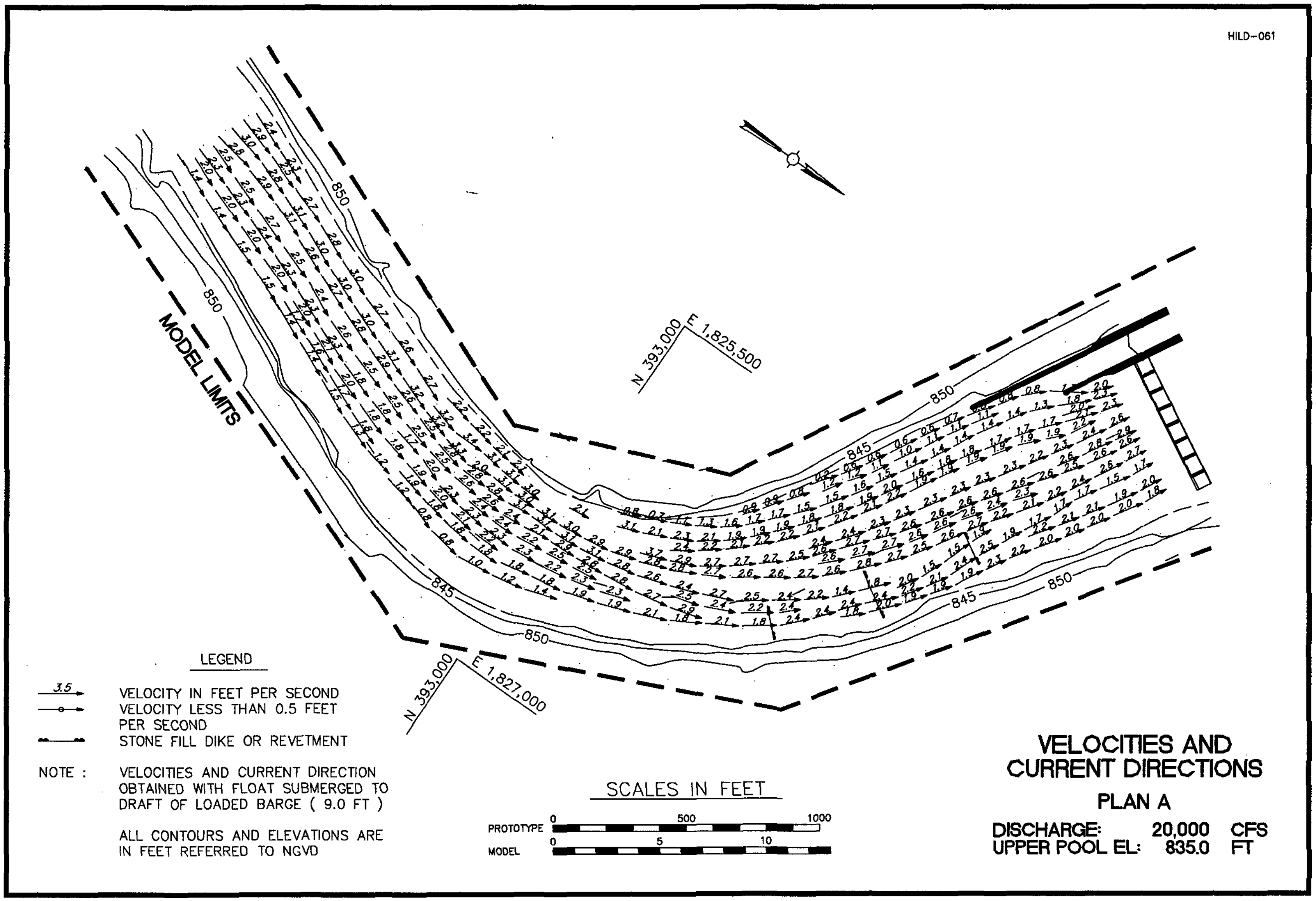
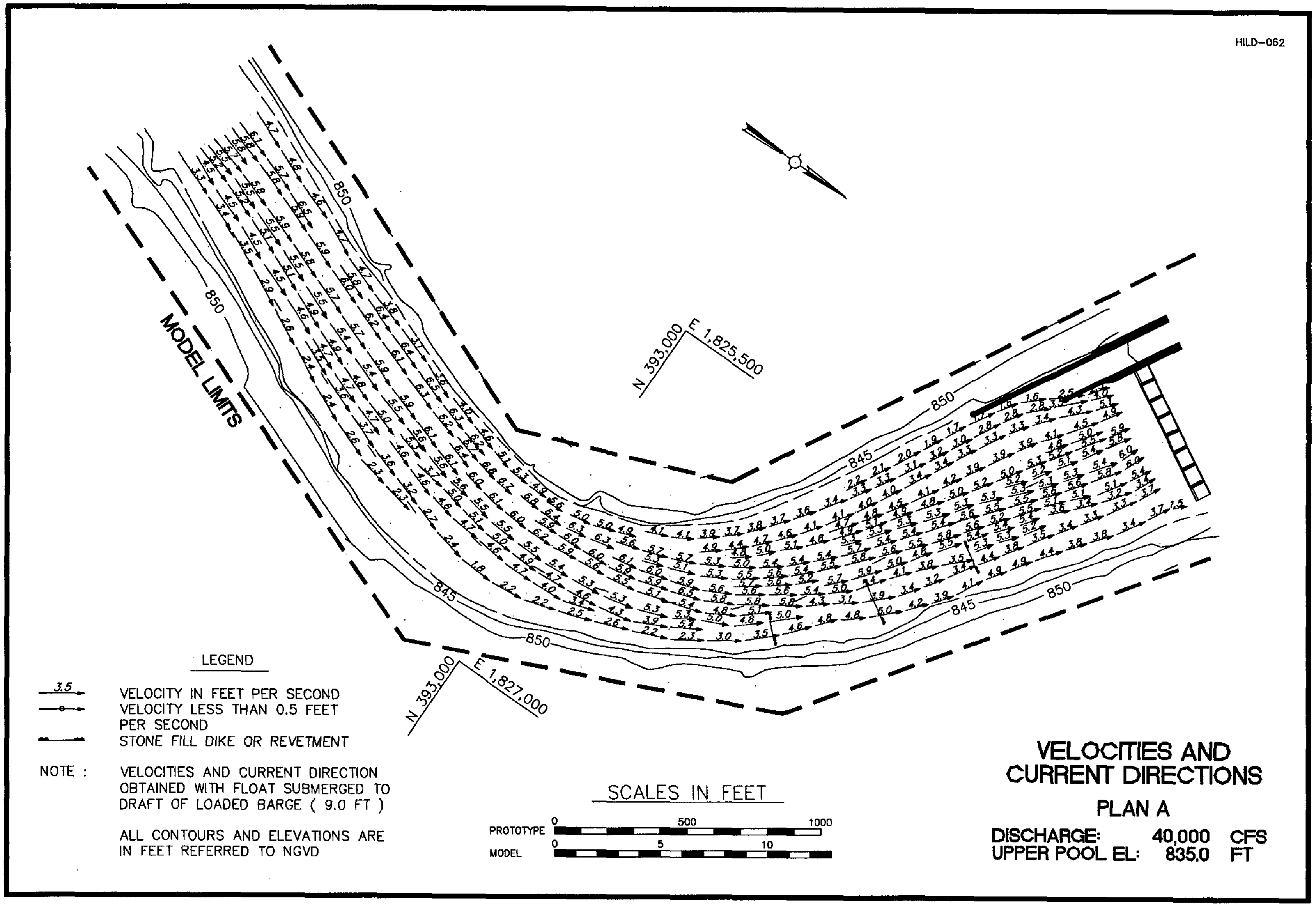
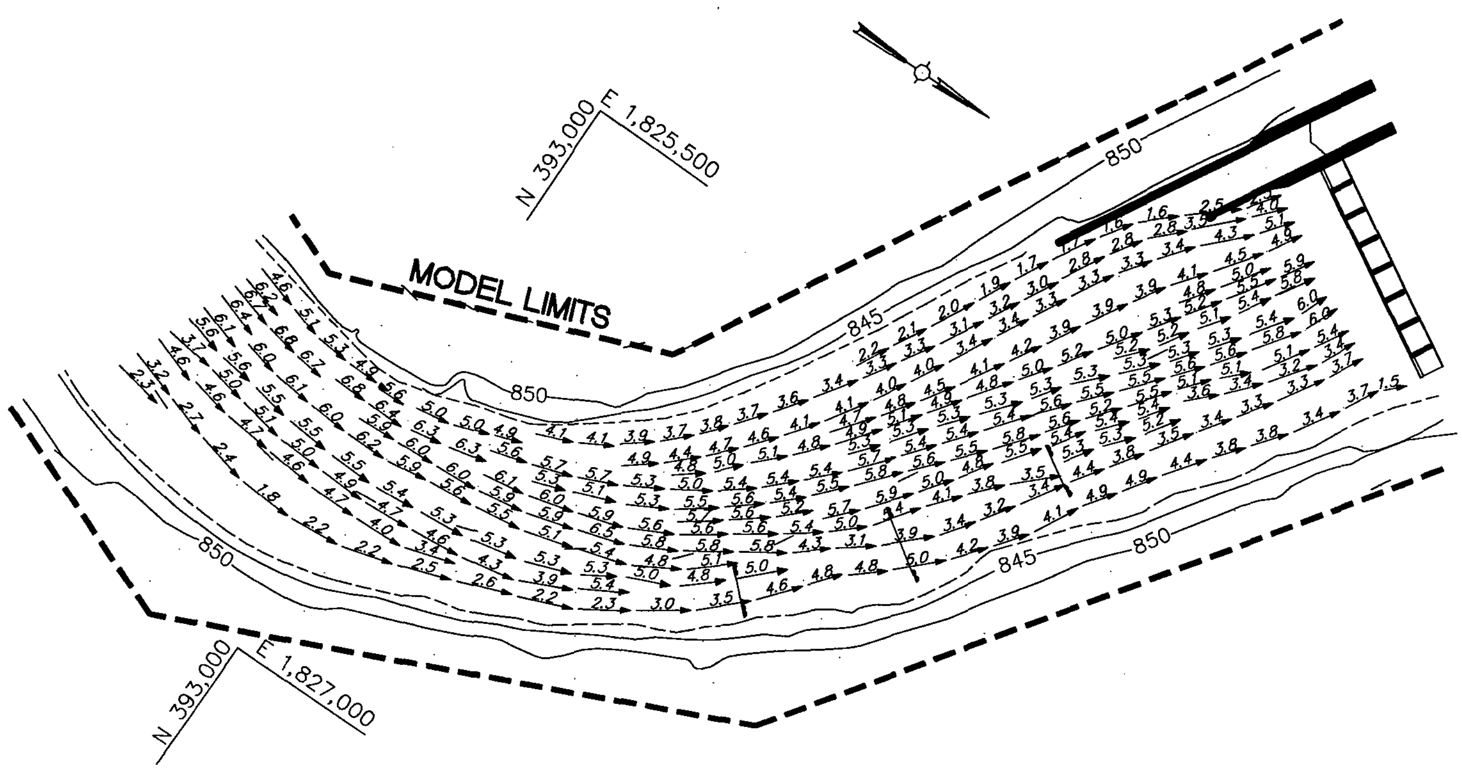

HILD-061
850
845
MODEL LIMITS
N 393,000
E 1,825,500
N 393,000
E 1,827,000
LEGEND
3.5
VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
STONE FILL DIKE OR REVETMENT
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
SCALES IN FEET
PROTOTYPE 0 500 1000
MODEL 0 5 10
VELOCITIES AND CURRENT DIRECTIONS
PLAN A
DISCHARGE: 20,000 CFS
UPPER POOL EL: 835.0 FT

Plate 36



HILD-062
MODEL LIMITS
850
845
N 393,000 E 1,825,500
N 393,000 E 1,827,000
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
STONE FILL DIKE OR REVETMENT
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
SCALES IN FEET
PROTOTYPE 0 500 1000
MODEL 0 5 10
VELOCITIES AND CURRENT DIRECTIONS
PLAN A
DISCHARGE: 40,000 CFS
UPPER POOL EL: 835.0 FT

HILD-075



LEGEND

3.5 — VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
STONE FILL DIKE OR REVETMENT

NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)

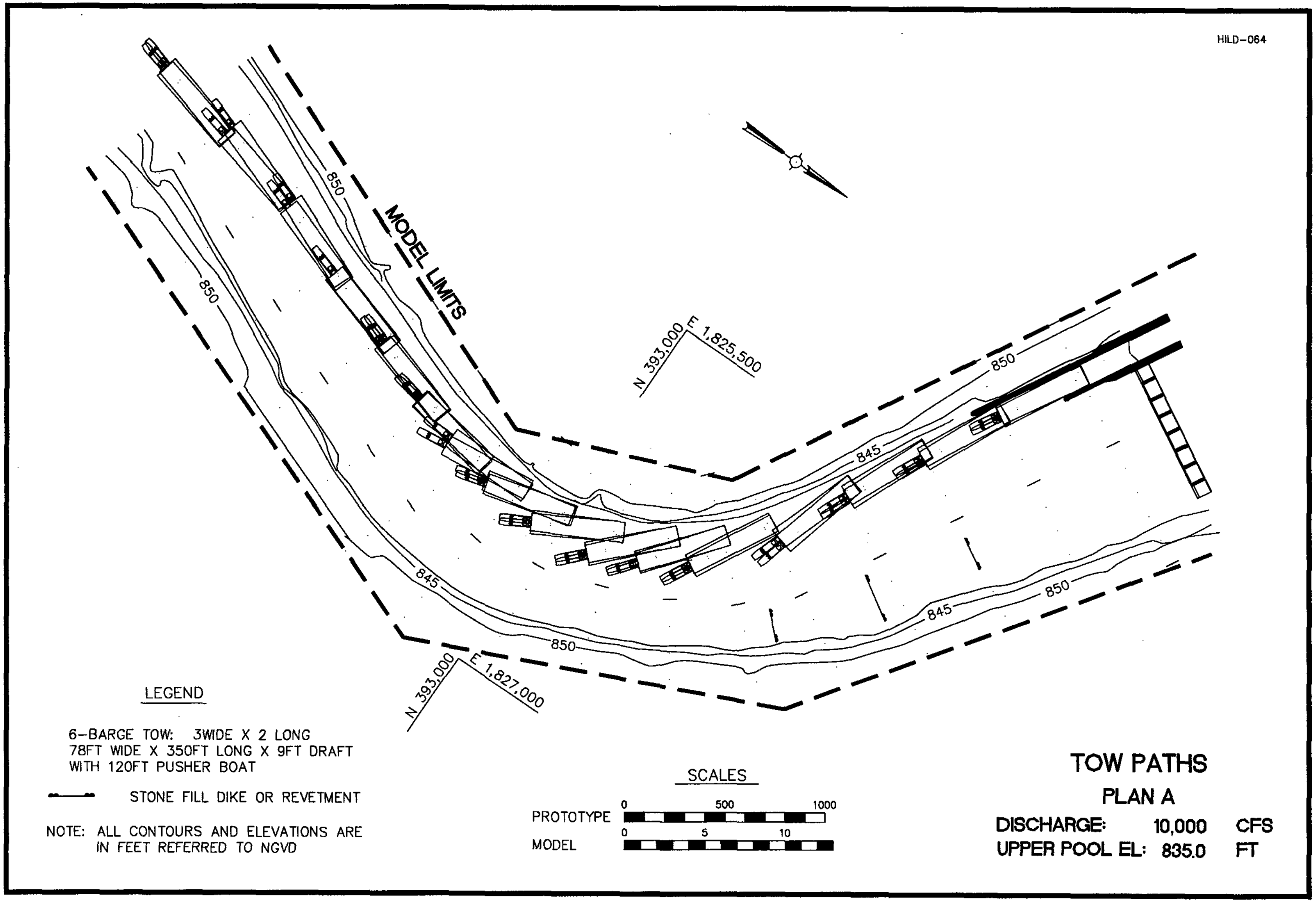
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES

PROTOTYPE 0 500 1000
MODEL 0 5 10

VELOCITIES AND CURRENT DIRECTIONS
PLAN A

DISCHARGE: 40,000 CFS
UPPER POOL: 835.0 FT


HILD-064
MODEL LIMITS
850
845
850
845
850
845
850
N 393,000
E 1,825,500
N 393,000
E 1,827,000
LEGEND
6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT
STONE FILL DIKE OR REVETMENT
NOTE: ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO NGVD
SCALES
PROTOTYPE 0 500 1000
MODEL 0 5 10
TOW PATHS
PLAN A
DISCHARGE: 10,000 CFS
UPPER POOL EL: 835.0 FT

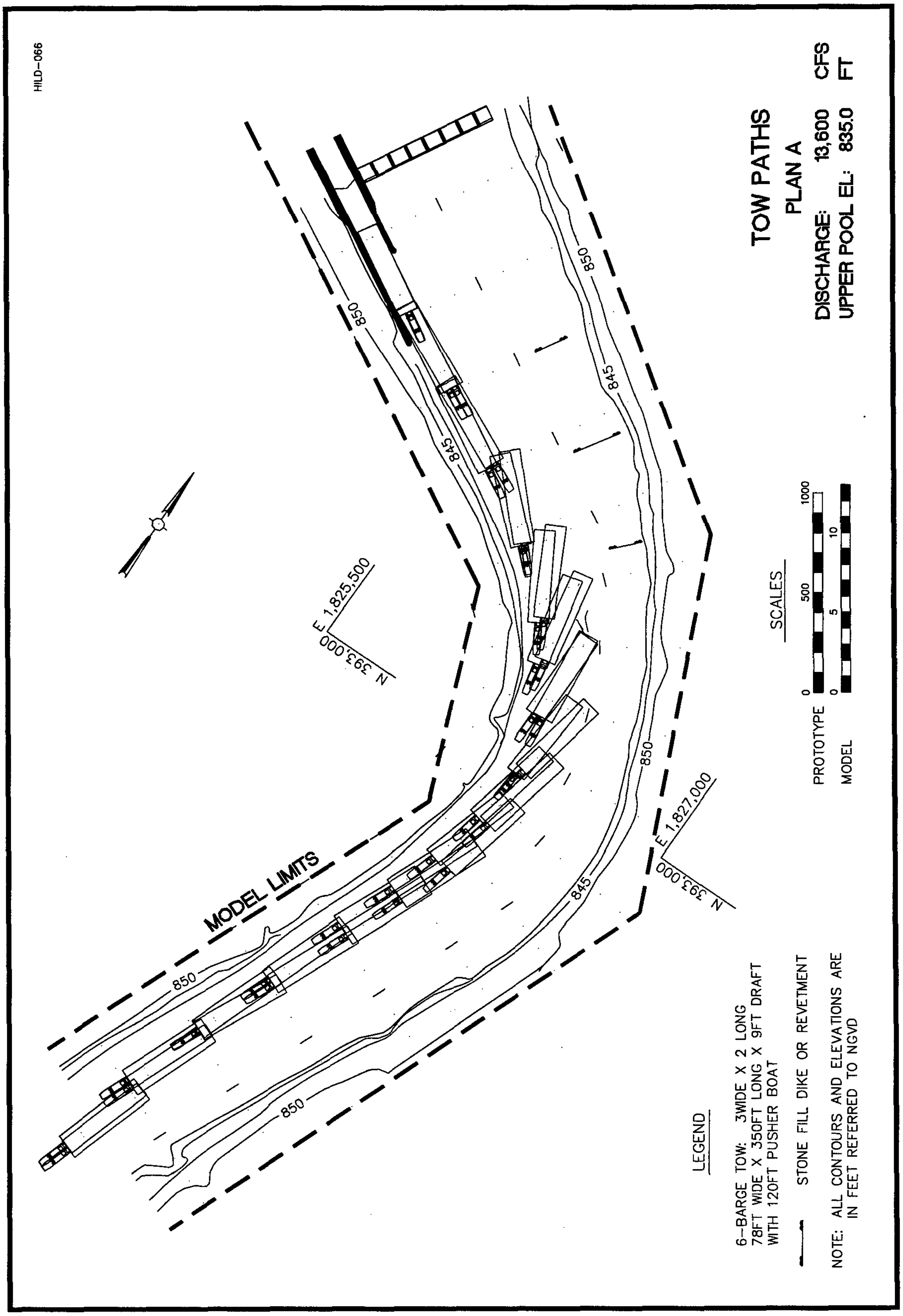
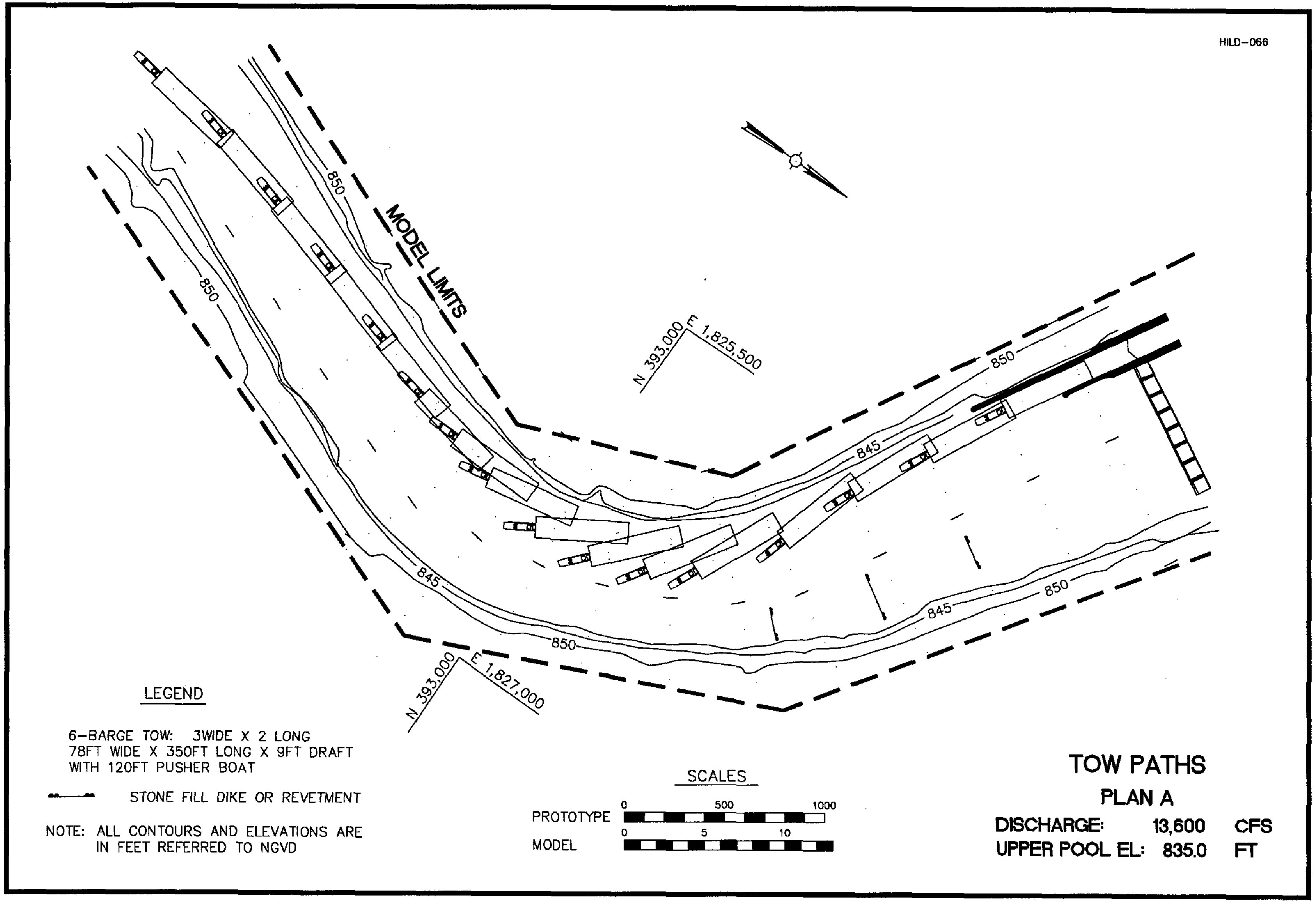
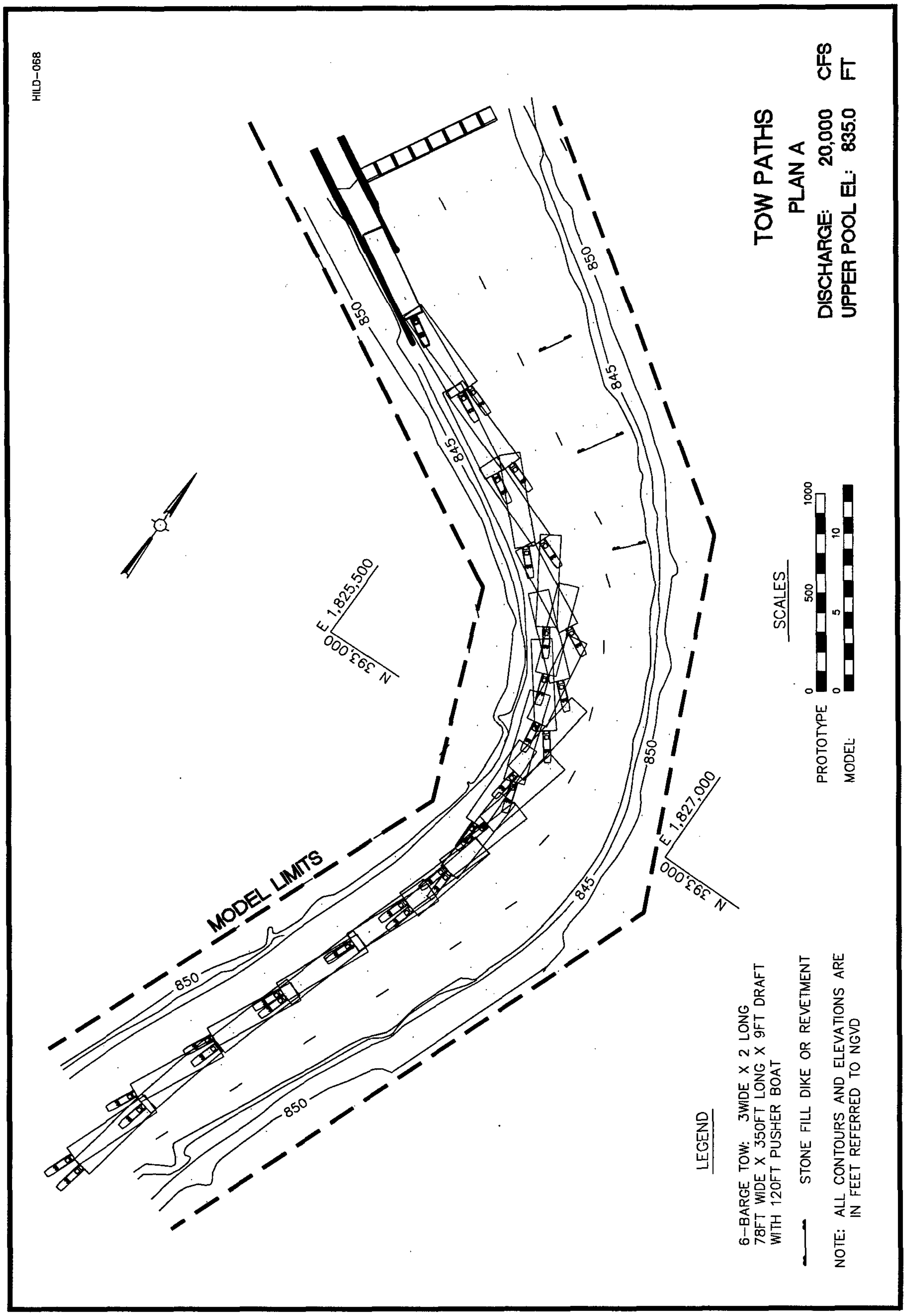

HILD-066
TOW PATHS
PLAN A
DISCHARGE: 13,600 CFS
UPPER POOL EL: 835.0 FT
SCALES
PROTOTYPE 0 500 1000
MODEL 0 5 10
MODEL LIMITS
E 1,825,500
N 393,000
E 1,827,000
N 393,000
850
845
LEGEND
6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT
STONE FILL DIKE OR REVETMENT
NOTE: ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO NGVD

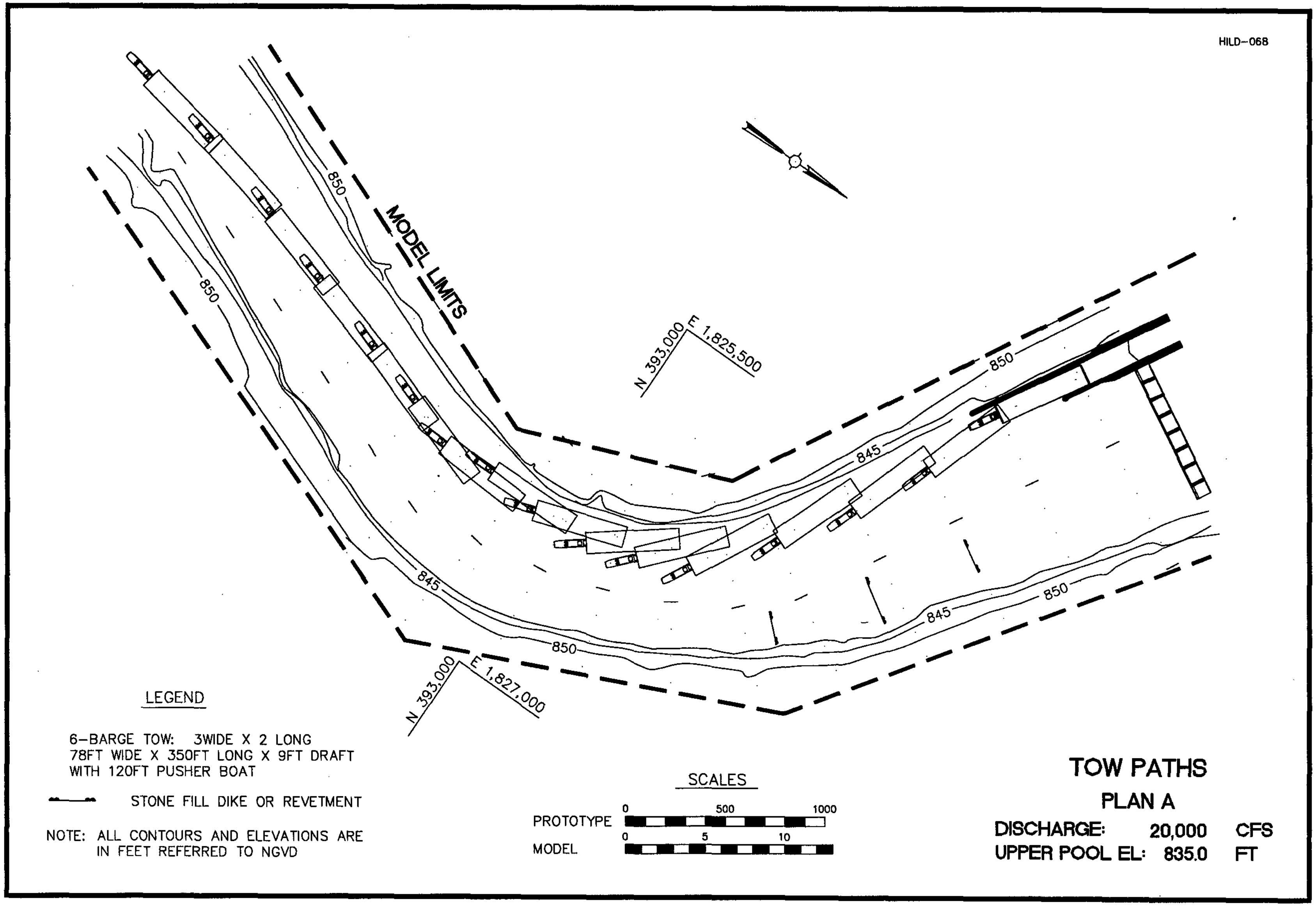
Plate 40

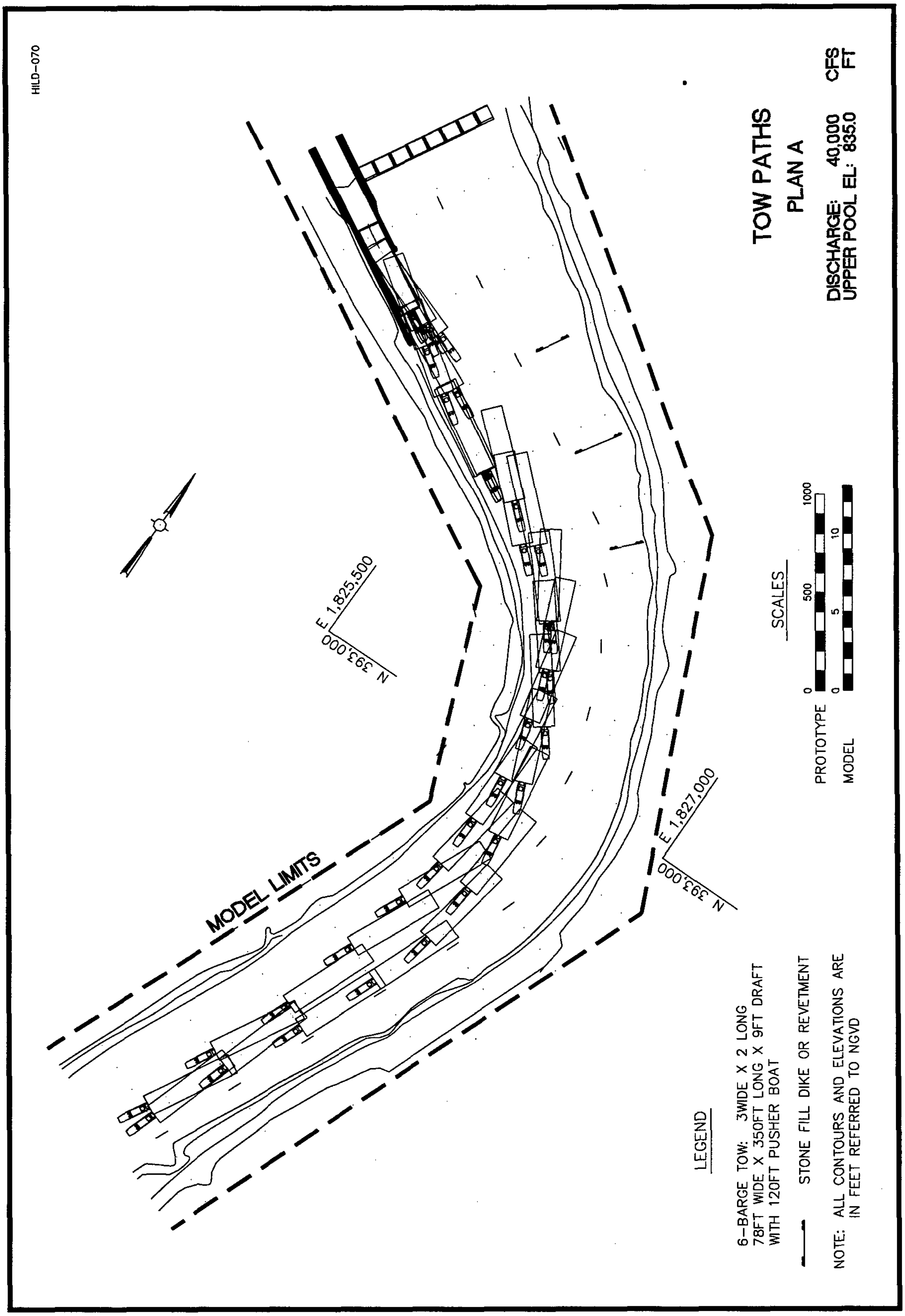

HILD-066
MODEL LIMITS
850
845
850
845
850
845
850
N 393,000
E 1,825,500
N 393,000
E 1,827,000
LEGEND
6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT
STONE FILL DIKE OR REVETMENT
NOTE: ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO NGVD
SCALES
PROTOTYPE 0 500 1000
MODEL 0 5 10
TOW PATHS
PLAN A
DISCHARGE: 13,600 CFS
UPPER POOL EL: 835.0 FT



HILD-068
TOW PATHS
PLAN A
DISCHARGE: 20,000 CFS
UPPER POOL EL: 835.0 FT
MODEL LIMITS
850
845
E 1,825,500
N 393,000
E 1,827,000
N 393,000
SCALES
PROTOTYPE 0 500 1000
MODEL 0 5 10
LEGEND
6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT
STONE FILL DIKE OR REVETMENT
NOTE: ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO NGVD

Plate 42


HILD-068
MODEL LIMITS
850
845
850
845
850
845
850
845
N 393,000
E 1,825,500
N 393,000
E 1,827,000
LEGEND
6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT
STONE FILL DIKE OR REVETMENT
NOTE: ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO NGVD
SCALES
PROTOTYPE 0 500 1000
MODEL 0 5 10
TOW PATHS
PLAN A
DISCHARGE: 20,000 CFS
UPPER POOL EL: 835.0 FT



HILD-070
TOW PATHS
PLAN A
DISCHARGE: 40,000 CFS
UPPER POOL EL: 835.0 FT
SCALES
PROTOTYPE 0 500 1000
MODEL 0 5 10
MODEL LIMITS
E 1,825,500
N 393,000
E 1,827,000
N 393,000
LEGEND
6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT
STONE FILL DIKE OR REVETMENT
NOTE: ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO NGVD

Plate 44

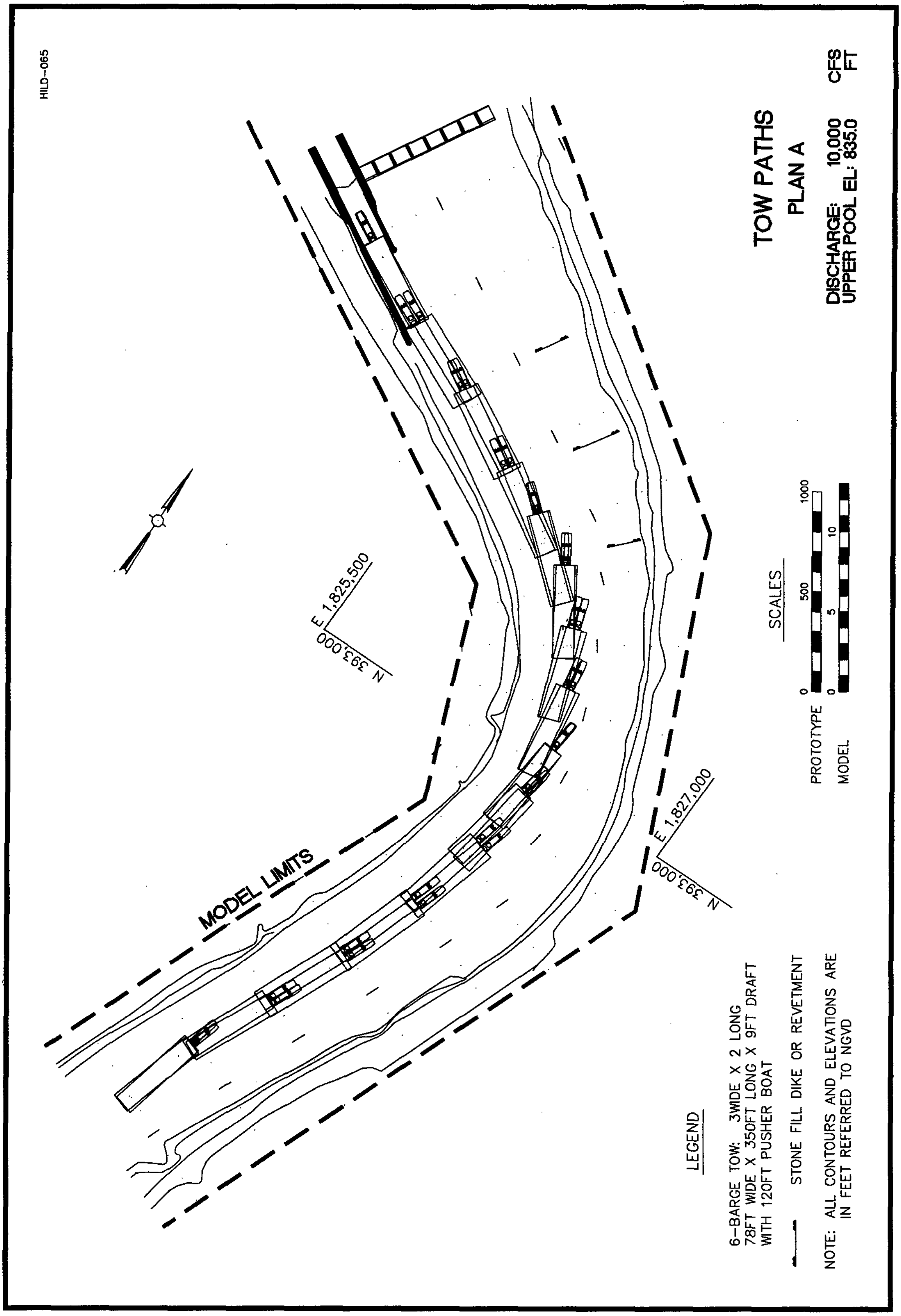

HILD-065
TOW PATHS
PLAN A
DISCHARGE: 10,000 CFS
UPPER POOL EL: 835.0 FT
MODEL LIMITS
E 1,825,500
N 393,000
E 1,827,000
N 393,000
SCALES
PROTOTYPE 0 500 1000
MODEL 0 5 10
LEGEND
6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT
STONE FILL DIKE OR REVETMENT
NOTE: ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO NGVD

Plate 45

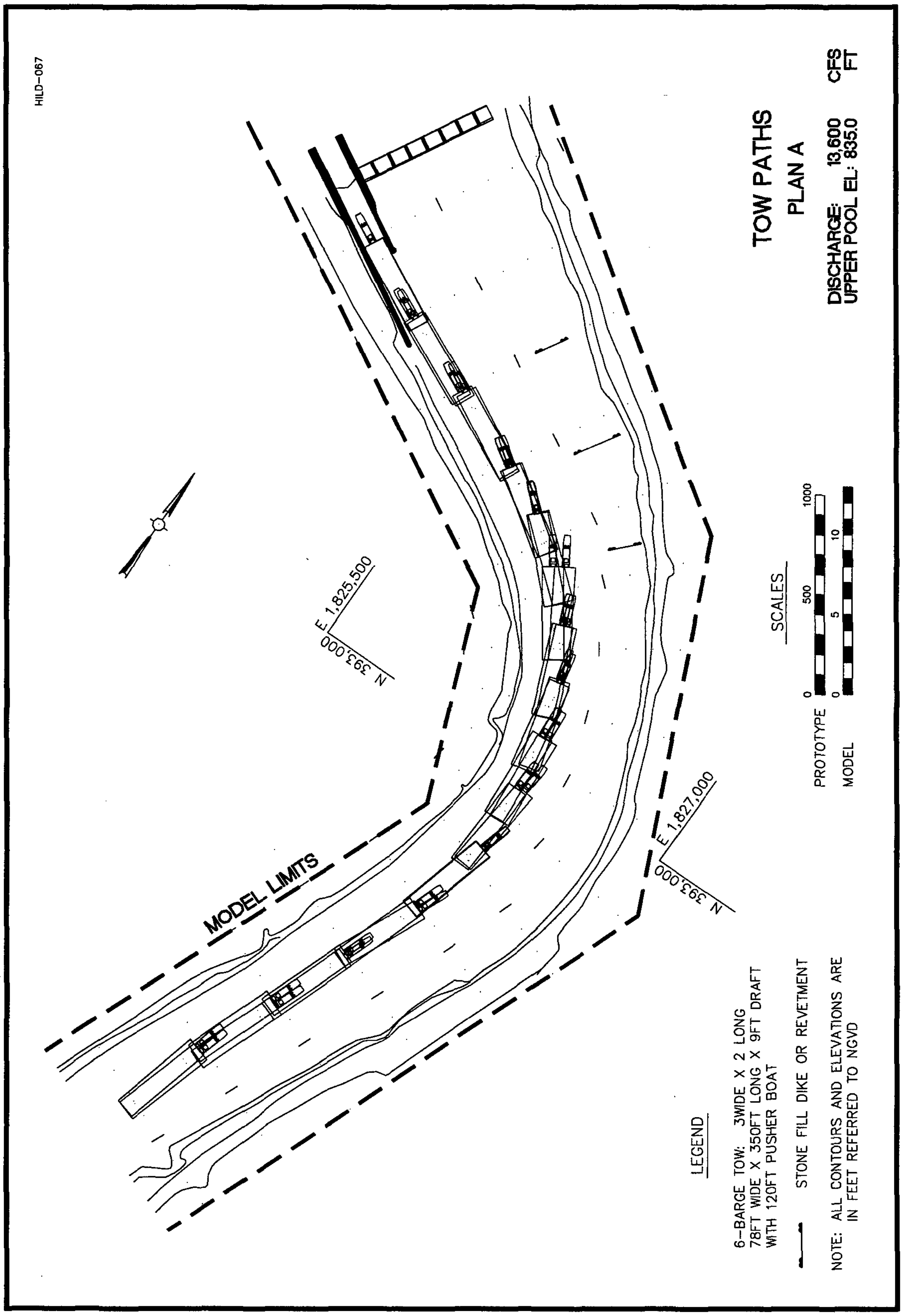
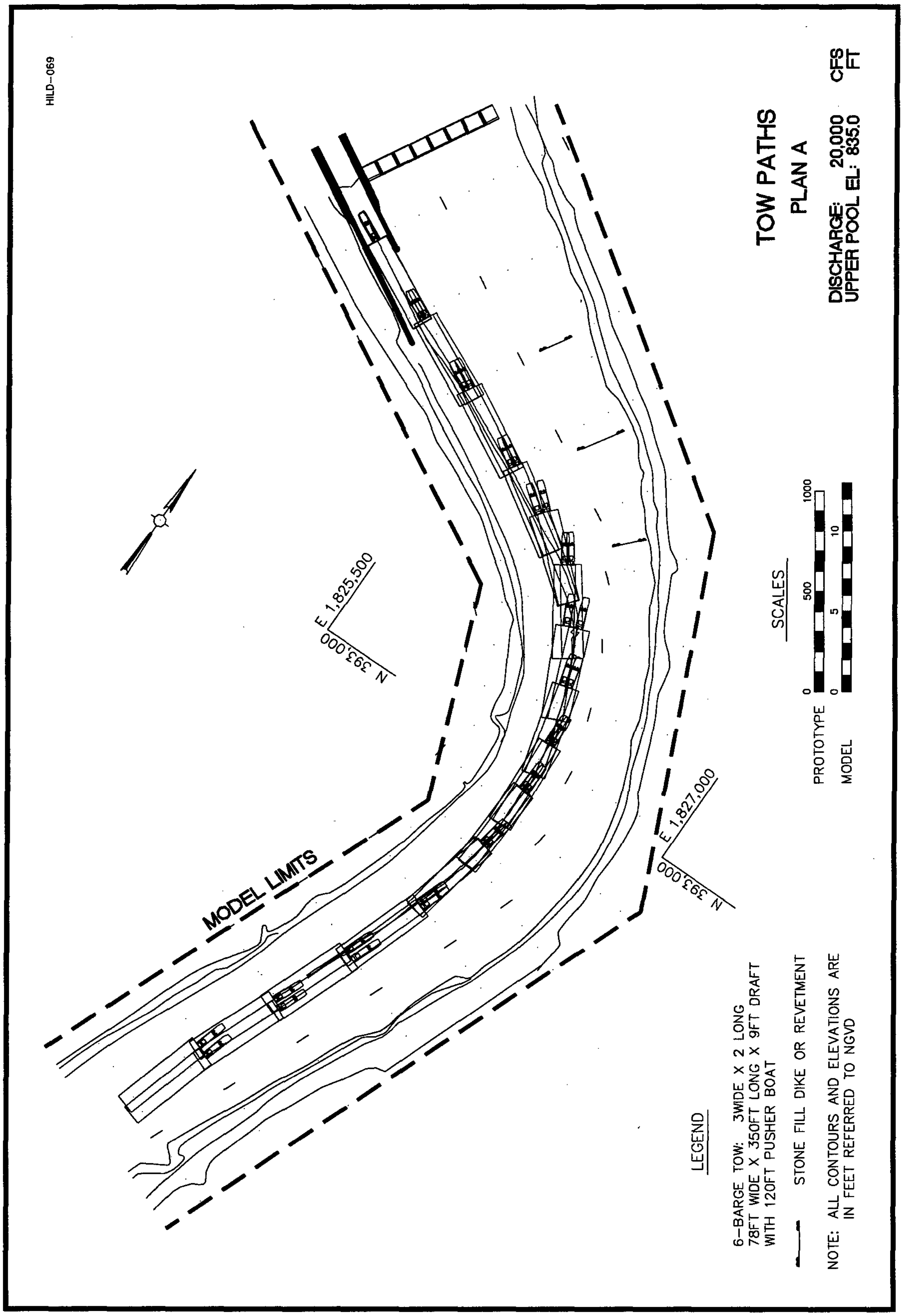
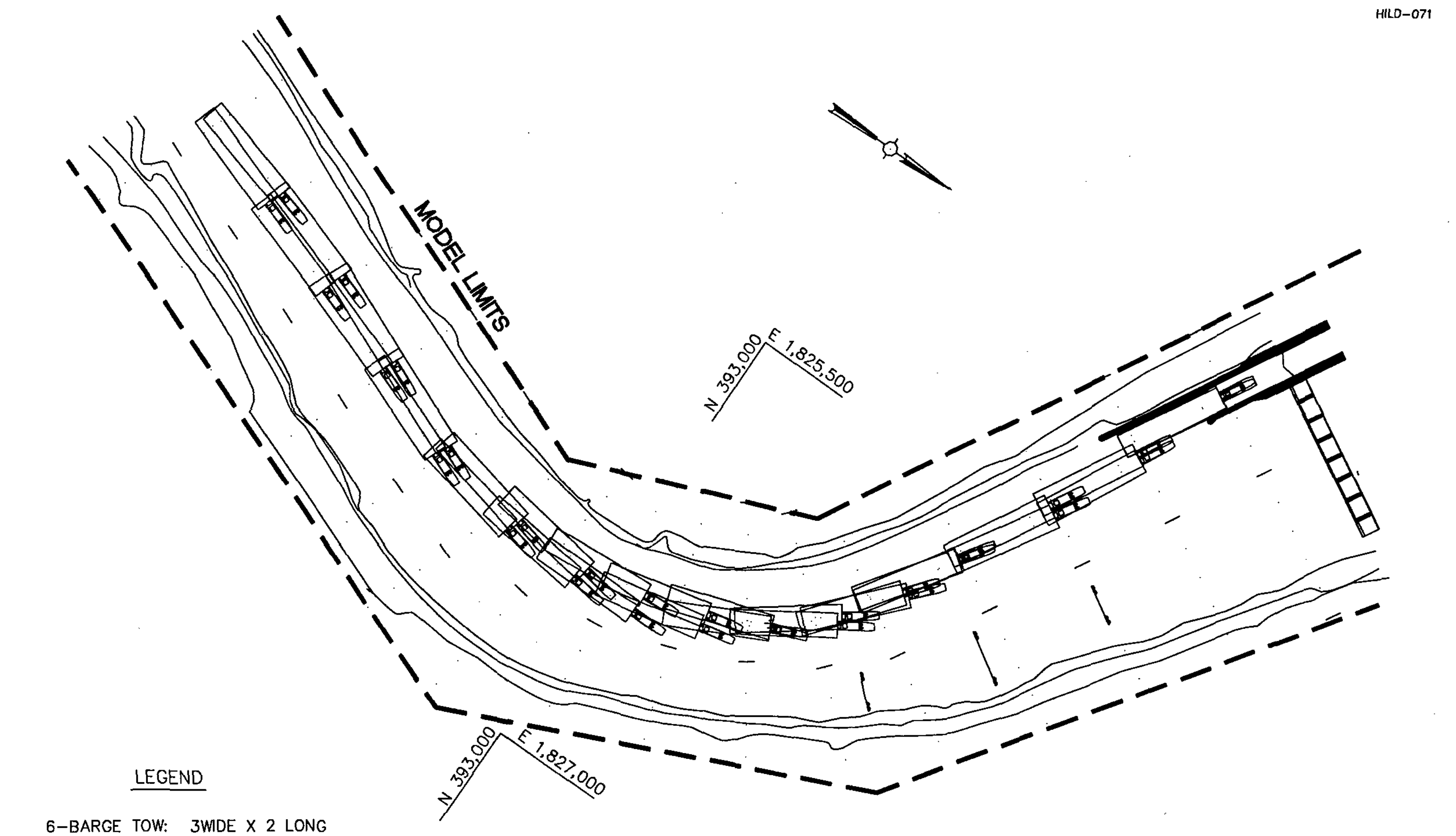

HILD-067
TOW PATHS
PLAN A
DISCHARGE: 13,600 CFS
UPPER POOL EL: 835.0 FT
MODEL LIMITS
E 1,825,500
N 393,000
E 1,827,000
N 393,000
SCALES
PROTOTYPE 0 500 1000
MODEL 0 5 10
LEGEND
6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT
STONE FILL DIKE OR REVETMENT
NOTE: ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO NGVD

Plate 46


HILD-069
TOW PATHS
PLAN A
DISCHARGE: 20,000 CFS
UPPER POOL EL: 835.0 FT
MODEL LIMITS
E 1,825,500
N 393,000
E 1,827,000
N 393,000
SCALES
PROTOTYPE 0 500 1000
MODEL 0 5 10
LEGEND
6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT
STONE FILL DIKE OR REVETMENT
NOTE: ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO NGVD



LEGEND

6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT

STONE FILL DIKE OR REVETMENT

NOTE: ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES

PROTOTYPE 0 500 1000

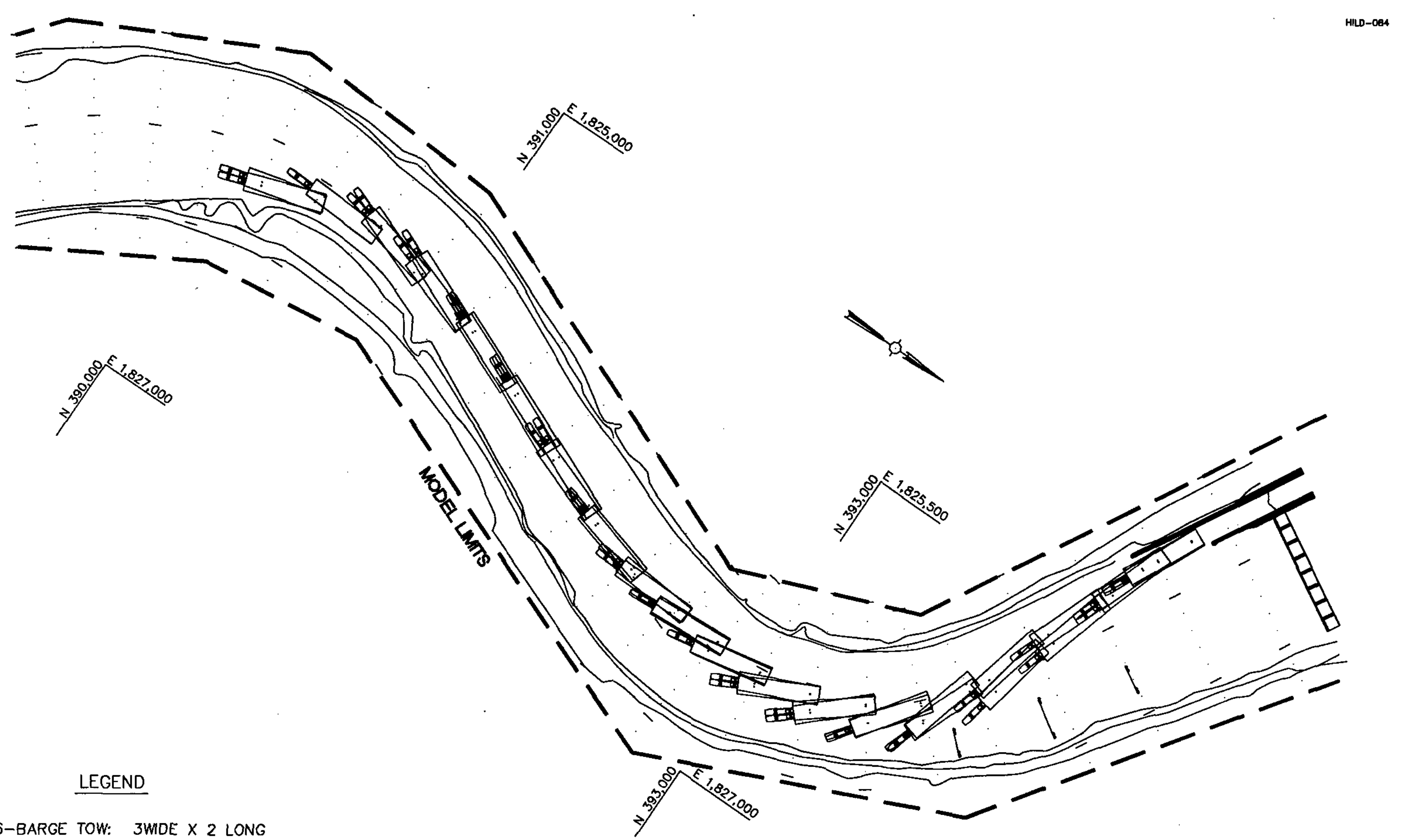
MODEL 0 5 10

TOW PATHS

PLAN A

DISCHARGE: 40,000 CFS
UPPER POOL EL: 835.0 FT

Plate 48



LEGEND

6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT

STONE FILL DIKE OR REVETMENT

NOTE: ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES IN FEET

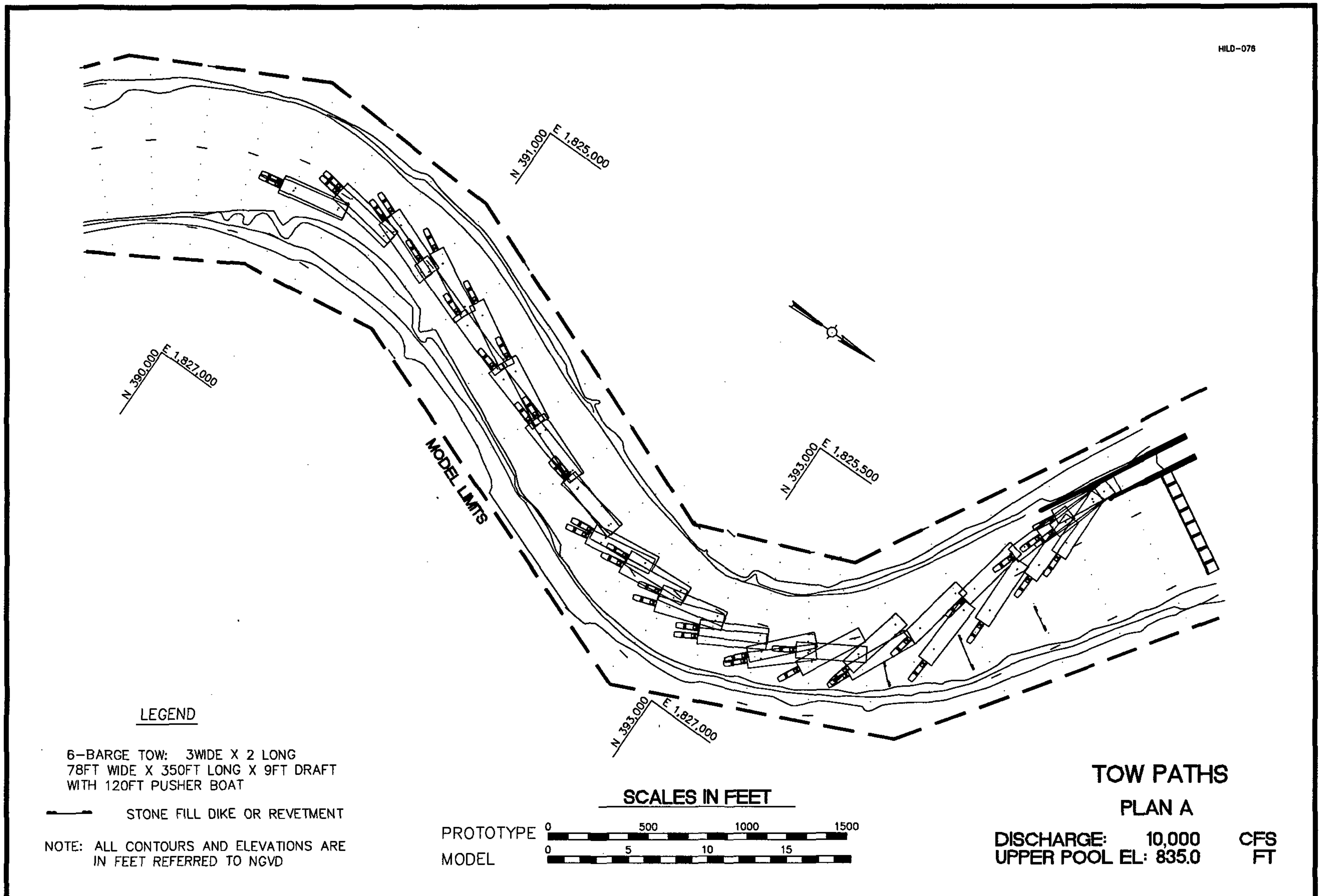
PROTOTYPE 0 500 1000 1500
MODEL 0 5 10 15

TOW PATHS

PLAN A

DISCHARGE: 5,000 CFS
UPPER POOL EL: 835.0 FT

Plate 49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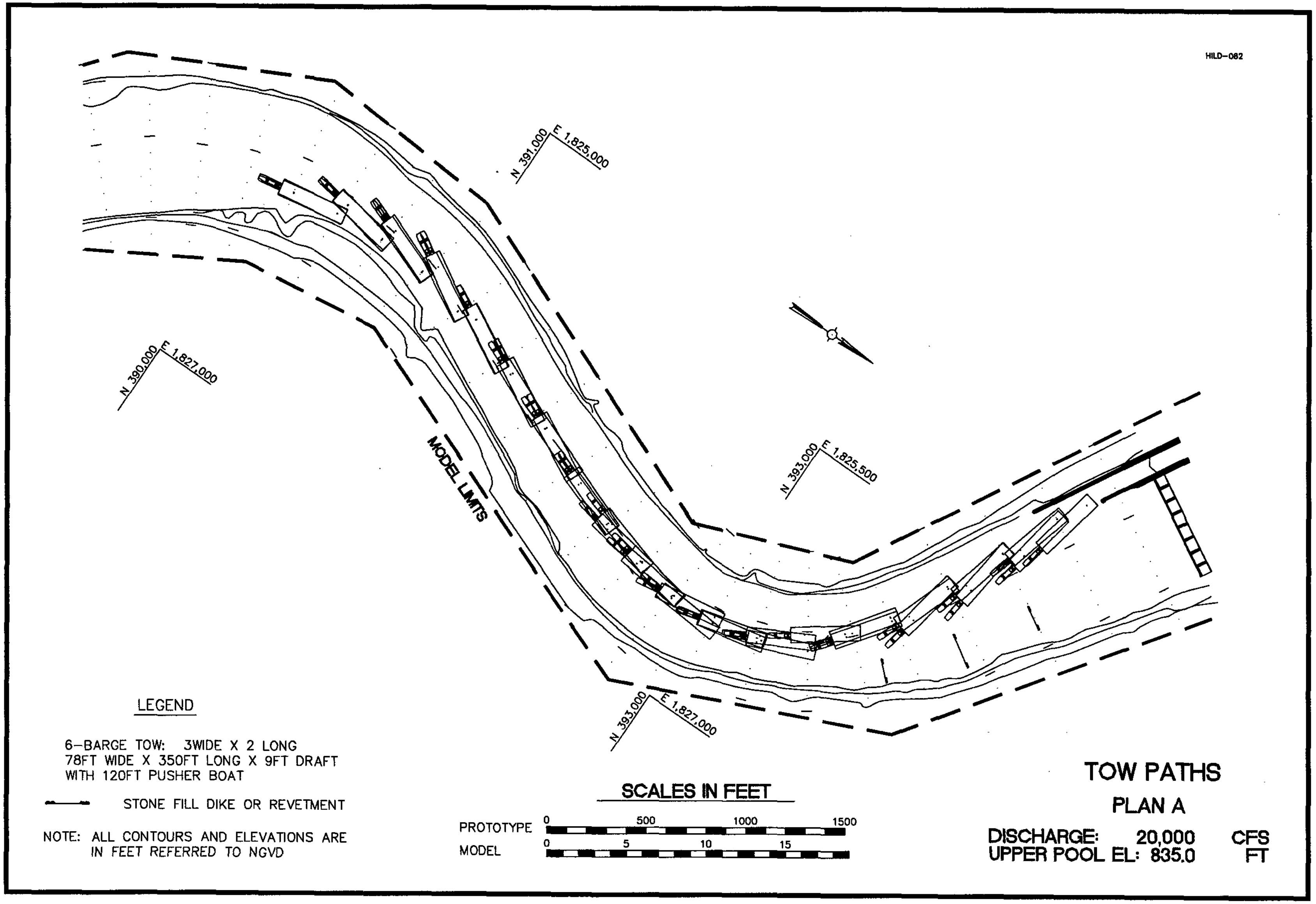
N 391,000 E 1,825,000
N 390,000 E 1,827,000
N 393,000 E 1,825,500
N 393,000 E 1,827,000
MODEL LIMITS
LEGEND
6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT
STONE FILL DIKE OR REVETMENT
NOTE: ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
SCALES IN FEET
PROTOTYPE 0 500 1000 1500
MODEL 0 5 10 15
TOW PATHS
PLAN A
DISCHARGE: 10,000 CFS
UPPER POOL EL: 835.0 FT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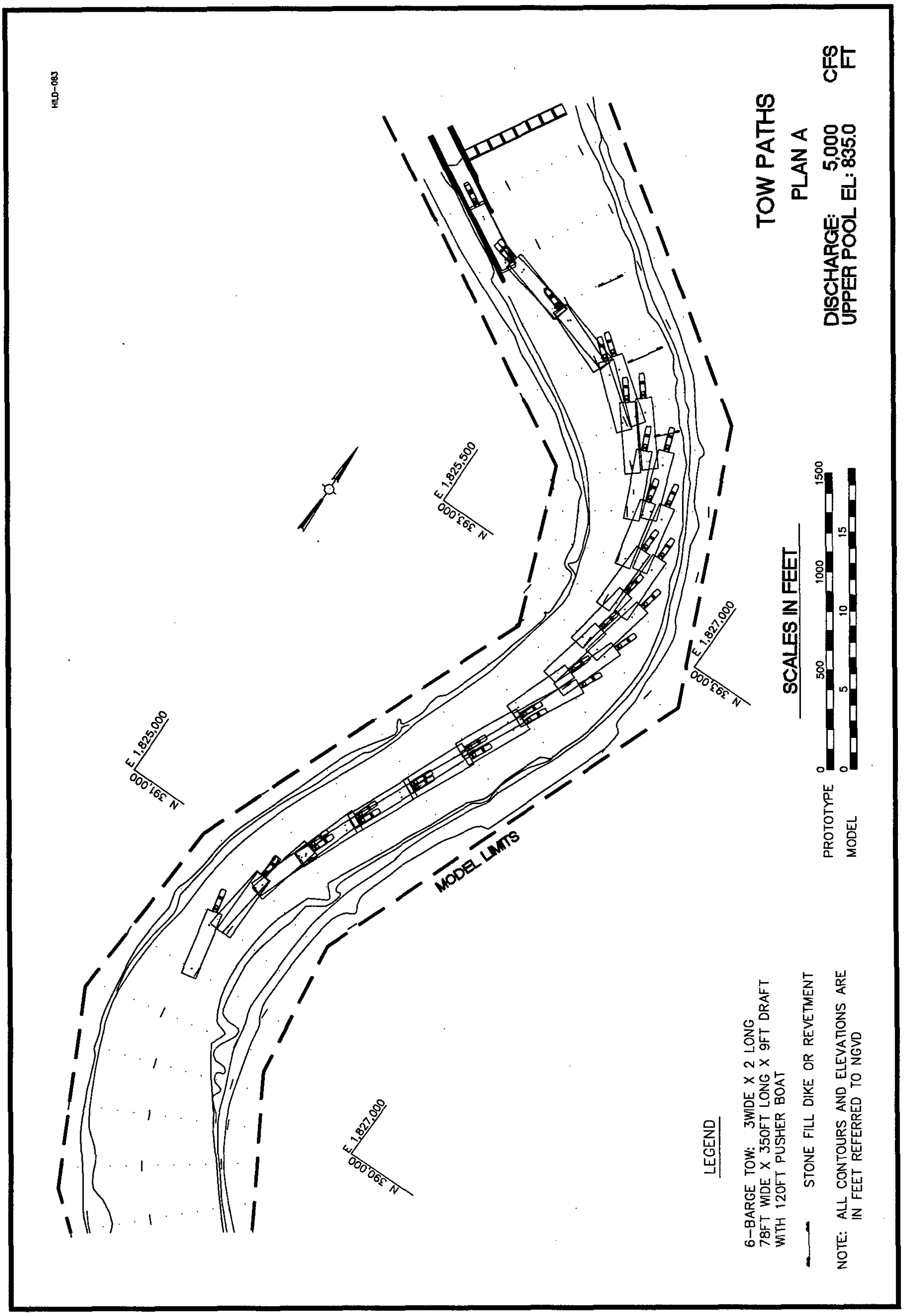
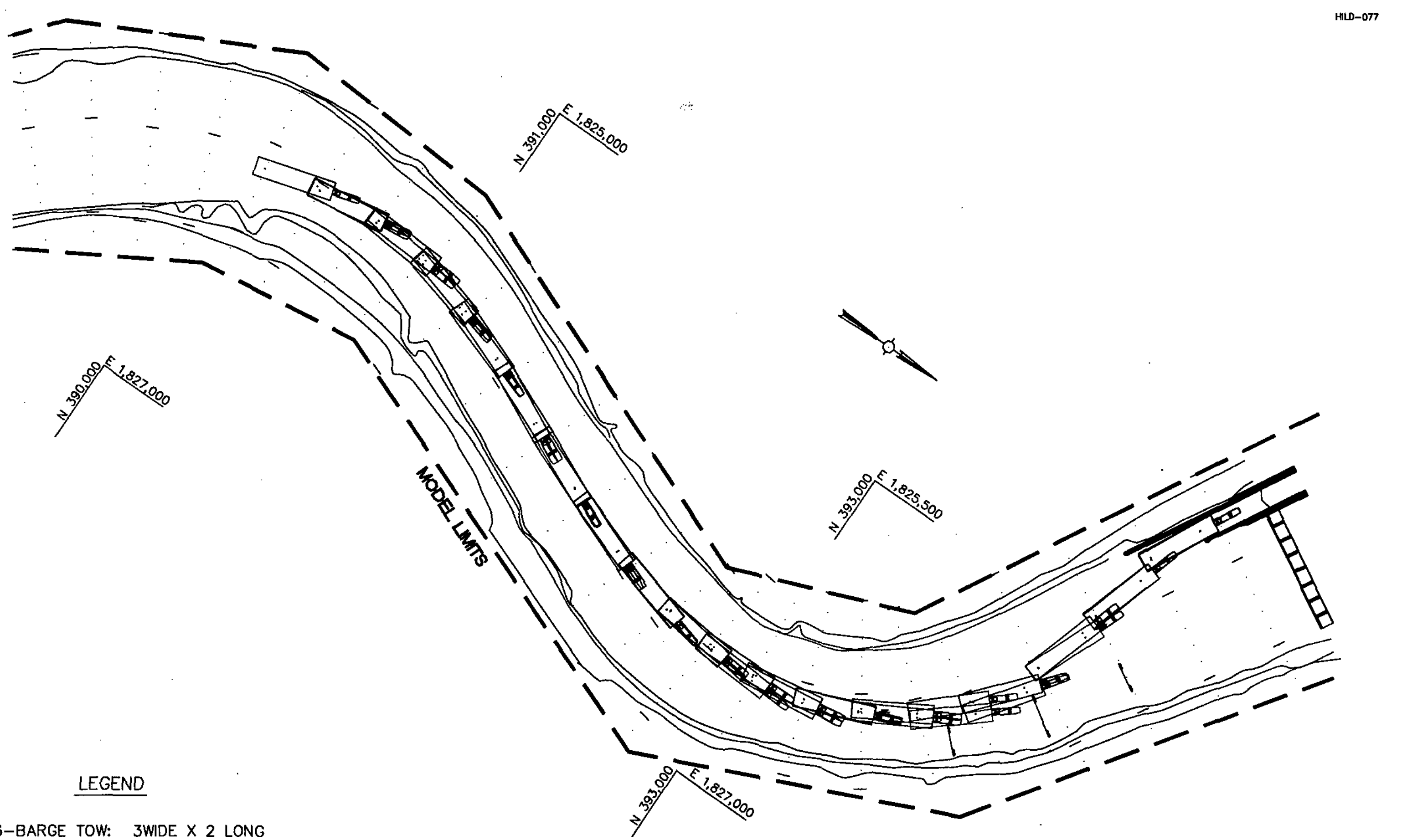
N 390,000 E 1,827,000
N 393,000 E 1,825,500
N 393,000 E 1,827,000
MODEL LIMITS
LEGEND
6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT
STONE FILL DIKE OR REVETMENT
NOTE: ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO NGVD
SCALES IN FEET
PROTOTYPE 0 500 1000 1500
MODEL 0 5 10 15
TOW PATHS
PLAN A
DISCHARGE: 20,000 CFS
UPPER POOL EL: 835.0 FT



HLD-083
TOW PATHS
PLAN A
DISCHARGE: 5,000 CFS
UPPER POOL EL: 835.0 FT
SCALES IN FEET
PROTOTYPE 0 500 1000 1500
MODEL 0 5 10 15
MODEL LIMITS
E 1,825,500
N 393,000
E 1,827,000
N 393,000
E 1,825,000
N 391,000
E 1,827,000
N 390,000
LEGEND
6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT
STONE FILL DIKE OR REVETMENT
NOTE: ALL CONTOURS AND ELEVATIONS ARE
IN FEET REFERRED TO NGVD

Plate 52



LEGEND

6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT

STONE FILL DIKE OR REVETMENT

NOTE: ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES IN FEET

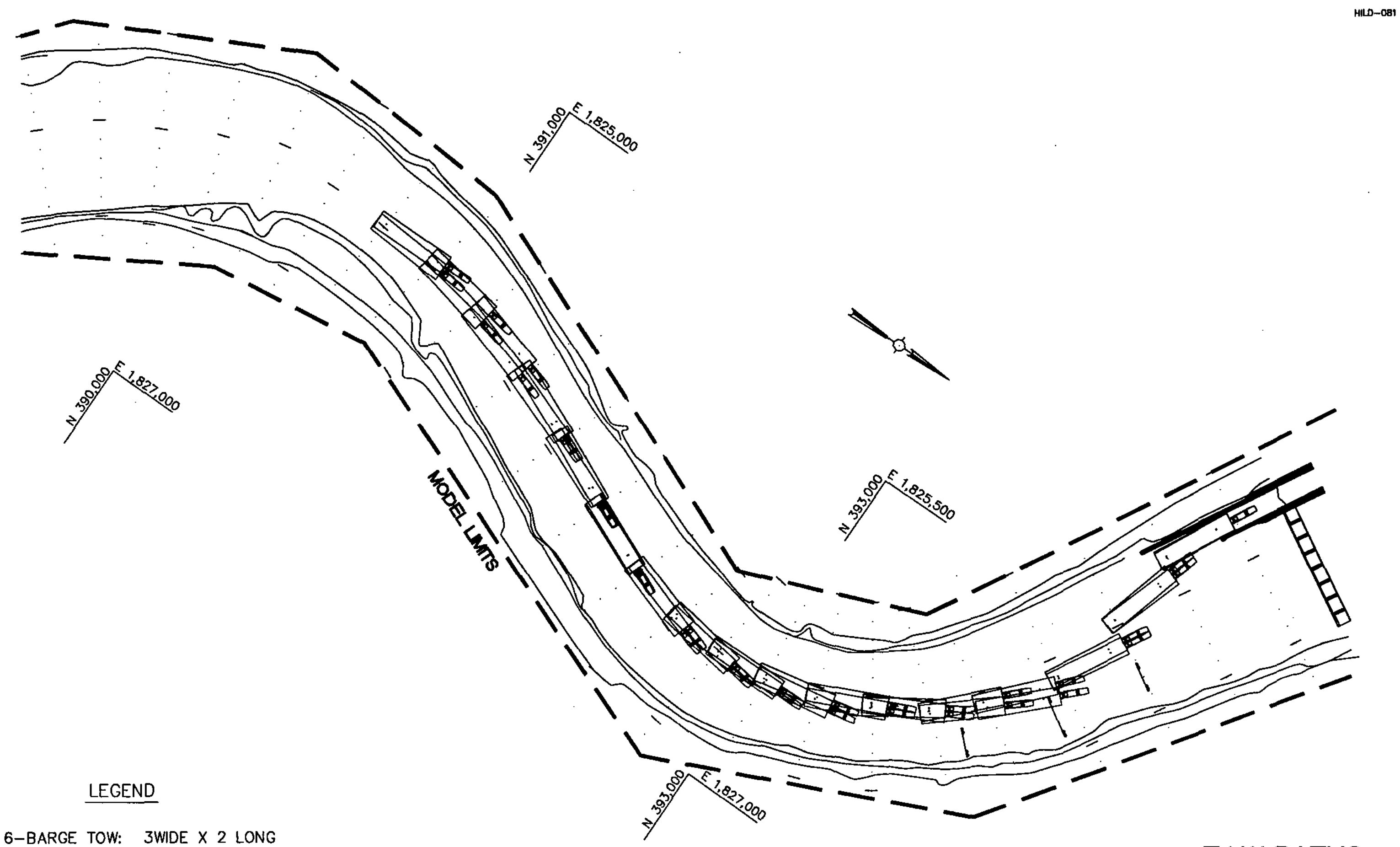
PROTOTYPE 0 500 1000 1500

MODEL 0 5 10 15

TOW PATHS

PLAN A

DISCHARGE: 10,000 CFS
UPPER POOL EL: 835.0 FT



LEGEND

6-BARGE TOW: 3WIDE X 2 LONG
78FT WIDE X 350FT LONG X 9FT DRAFT
WITH 120FT PUSHER BOAT

STONE FILL DIKE OR REVETMENT

NOTE: ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES IN FEET

PROTOTYPE 0 500 1000 1500

MODEL 0 5 10 15

TOW PATHS

PLAN A

DISCHARGE: 20,000 CFS
UPPER POOL EL: 835.0 FT

Plate 54

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
July 1999

3. REPORT TYPE AND DATES COVERED
Final report

4. TITLE AND SUBTITLE
Hildebrand Lock and Dam

5. FUNDING NUMBERS

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Waterways Experiment Station
3909 Halls Ferry Road, Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
Technical Report CHL-99-14

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Engineer District, Pittsburgh
William S. Moorhead Federal Building
1000 Liberty Avenue, Pittsburgh, PA 15222-4186

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Hildebrand Lock and Dam is located on the left descending bank of the Monongahela River about 108 miles above the "Point" at Pittsburgh, PA. Principal structures at the site include an 84-ft by 600-ft lock and a 530-ft-long gated dam. Because of the location of the Hildebrand project (downstream of a very sharp left-hand bend) and the uniqueness of the depositing sediments, both a physical model and a numerical model were used to develop a plan that would eliminate or reduce tendencies for fine-grain silts and clays, intermingled with leaves and organics, from deposition int he upper lock approach to the Hildebrand Lock. This report documents the study of flow patterns, the measurement of current magnitudes and directions, the observation of depositional tendencies, and the effects of currents on the model tow.

14. SUBJECT TERMS

Bonneville Locks and Dam	Current velocity
Columbia River	Navigation conditions
Current direction	Water-surface elevations

15. NUMBER OF PAGES
96

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		